

KNOTT'S

HANDBOOK FOR VEGETABLE GROWERS

FIFTH EDITION

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FIFTH EDITION

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The pace of change in our personal and business lives continues to accelerate at an ever increasing rate. Accordingly, it is necessary to periodically update information in a long-running reference such as *Handbook* for Vegetable Growers. Our goal in this revision is to provide up-to-date information on vegetable crops for growers, students, extension personnel, crop consultants, and all those concerned with commercial production and marketing of vegetables.

Where possible, information in the Fourth Edition has been updated or replaced with current information. New technical information has been added on World Vegetable Production, Best Management Practices, Organic Crop Production, Food Safety, Pesticide Safety, Postharvest Diseases, and Minimally Processed Vegetables. The Internet has become a valuable source of information since 1997. Hundreds of websites relating to vegetables are included in this edition and are available online at www.wiley.com/college/Knotts.

We are grateful to our colleagues who have provided materials, reviewed portions of the manuscript, and encouraged us in this revision. We especially acknowledge the assistance of Brian Benson, California Asparagus Seed and Transplants, Inc.; George Boyhan, University of Georgia; Wallace Chasson, Florida Department of Agriculture and Consumer Services; Steve Grattan, University of California; Tim Hartz, University of California; Richard Hassell, Clemson University; Larry Hollar, Hollar and Company; Adel Kader, University of California; Tom Moore, Harris-Moran Seed Co.; Stu Pettygrove, University of California; Steven Sargent, University of Florida; Pieter Vandenberg, Seminis Vegetable Seeds; and Jim Watkins, Nunhems USA.

We appreciate the outstanding assistance provided by Wiley editor Jim Harper, Senior Production Editor Millie Torres, and the attention to details and good humor in the preparation of this manuscript by Gail Maynard.

We hope that *Handbook for Vegetable Growers* will continue to be the timely and useful reference for those with interest in vegetable crops envisioned by Dr. J. E. Knott when it was first published in 1956. James E. Knott (1897–1977) was a Massachusetts native. He earned a B.S. degree at Rhode Island State College and an M.S. and Ph.D. at Cornell University. After distinguished faculty and administrative service at Pennsylvania State College and Cornell University he moved to the University of California, Davis, where he was administrator of the Vegetable Crops Department from 1940 to 1964. The department grew in numbers and stature to be one of the world's best vegetable centers. Dr. Knott was president of the American Society for Horticultural Science in 1948 and was made a Fellow in 1965.

Oscar A. Lorenz (1914–1994), senior author of the Second Edition (1980) and the Third Edition (1988) of *Handbook for Vegetable Growers*, was a native of Colorado. He earned a B.S. degree from Colorado State College and a Ph.D. from Cornell University before joining the University of California, Davis faculty in 1941. For the next 41 years he was an esteemed scientist and administrator at both the Riverside and Davis campuses. His research on vegetable

crops nutrition was the first to establish the relationship between soil fertility, leaf nutrient composition, and yield. This concept has been used successfully by growers throughout the world. Oscar was recognized as a Fellow of the American Society for Horticultural Science and of the American Society of Agronomy and Soil Science Society of America, and received numerous industry awards. He was a friend to all and a personal mentor to me. (DNM)

DONALD N. MAYNARD GEORGE J. HOCHMUTH

PART

1

VEGETABLES AND THE VEGETABLE INDUSTRY

- 01 BOTANICAL NAMES OF VEGETABLES NAMES OF VEGETABLES IN NINE LANGUAGES
- 02 EDIBLE FLOWERS
- 03 U.S. VEGETABLE PRODUCTION
- 04 CONSUMPTION OF VEGETABLES IN THE U.S.
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- 06 NUTRITIONAL COMPOSITION OF VEGETABLES

TABLE 1.1. BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS BOTANICAL NAMES OF VEGETABLES VEGETABLES

| Botanical Name | Common Name | Edible Plant Part |
|---|-------------------------|-------------------|
| Division Sphendophyta | | |
| Equisetaceae | HORSETAIL FAMILY | |
| Equisetum arvense L. | Horsetail | Young strobili |
| Division Pterophyta | FERN GROUP | |
| Dennstaedtiaceae | | |
| Pteridium aquilinum (L.) Kuhn. | Bracken fern | Immature frond |
| Osmundaceae | | |
| Osmunda cinnamomea L. | Cinnamon fern | Immature frond |
| Osmunda japonica Th. | Japanese flowering fern | Immature frond |
| Parkeriaceae | | |
| Ceratopteris thalictroides (L.) Brongn. | Water fern | Young leaf |
| Polypodiaceae | | |
| Diplazium esculentum (Retz.) Swartz. | Vegetable fern | Young leaf |
| Division Anthophyta | | |
| Class Monocotyledons | | |
| Alismataceae | WATER PLANTAIN FAMILY | |
| Sagittaria sagittifolia L. | Arrowhead | Corm |
| Sagittaria trifolia L. (Sieb.) Ohwi | Chinese arrowhead | Corm |

| Bulb and leaf Pseudostem Pseudostem and leaf Pseudostem and leaf | Bulb Aerial bulb Bulb Pseudostem and leaf | Leaf Bulb and leaf Leaf Leaf and bulb Leaf, immature flower Bulb, leaf | Corm, immature leaf, petiole Corm Corm, immature leaf Corm | Immature leaf Corm and young leaf Rhizome |
|---|---|--|---|---|
| ONION FAMILY Great-headed garlic Kurrat Leek Shallot | Onion Tree onion, Egyptian onion Rakkyo Welsh onion, Japanese hunching onion | Japanese garlic Garlic Chive Sand leek, giant garlic Chinese chive Longroot onion Turfed stone leek ARUM FAMILY | Giant taro, alocasia Elephant yam Taro, dasheen, cocoyam Giant swamp taro | Tannier spinach, catalou Tannia, yellow yautia CANNA FAMILY Indian canna, arrowroot, edible canna |
| Alliaceae Allium ampeloprasum L. Ampeloprasum group Allium ampeloprasum L. Kurrat group Allium ampeloprasum L. Porrum group Allium cepa L. Aggregatum group | Allium cepa L. Cepa group Allium cepa L. Proliferum group Allium chinense G. Don. Allium fistulosum L. | Allium grayi Regel Allium sativum L. Allium schoenoprasum L. Allium scorodoprasum L. Allium tuberosum Rottler ex Sprengel Allium victorialis L. var. platyphyllum, Hult. Allium × wakegi Araki | Alocasia macrorrhiza (L.) Schott Amorphophallus paeoniifolius (Dennst.) Nicolson Colocasia esculenta (L.) Schott Cyrtosperma chamissonis (Schott) Merr. Cyrtosperma merkusii (Hassk.) Schott. | Xanthosoma brasiliense (Desf.) Engler Xanthosoma sagittifolium (L.) Schott Cannaceae Canna indica L. |

TABLE 1.1. BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS VEGETABLES (Continued)

| Botanical Name | Common Name | Edible Plant Part |
|---|-------------------------|------------------------|
| | | |
| Cyperaceae | SEDGE FAMILY | |
| Cyperus esculentus L. | Rushnut, chufa | Tuber |
| Eleocharis dulcis (Burm.f.) Trin. ex Henschel | Water chestnut, Chinese | Corm |
| | water chestnut | |
| Eleocharis kuroguwai Ohwi | Wild water chestnut | Corm |
| Dioscoreaceae | YAM FAMILY | |
| Dioscorea alata L. | White yam, water yam | Tuber |
| Dioscorea batatas Decue. | Chinese yam | Tuber |
| Dioscorea bulbifera L. | Potato yam, aerial yam | Tuber |
| Dioscorea cayenensis Lam. | Yellow yam | Tuber |
| Dioscorea dumetorum (Kunth) Pax. | Bitter yam | Tuber |
| Dioscorea esculenta (Lour.) Burk. | Lesser yam | Tuber |
| Dioscorea rotundata Poir. | White Guinea yam | Tuber |
| Dioscorea trifida L. f. | Indian yam | Tuber |
| Iridaceae | IRIS FAMILY | |
| Tigridia pavonia KerGawl. | Common tiger flower | Bulb |
| Liliaceae | LILY FAMILY | |
| Asparagus acutifolius L. | Wild asparagus | Shoot |
| Asparagus officinalis L. | Asparagus | Shoot |
| $Hemerocallis\ { m spp}.$ | Daylily | Flower |
| Leopoldia comosa (L.) Parl. | Tuffed hyacinth | Bulb |
| $Lilium { m spp.}$ | Lily | Bulb |

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| BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS | |
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| ION NAM | |
| ES, COMIN | ontinued) |
| BOTANICAL NAMES | BLES (Co) |
| BOTANI | VEGETABLES (Co |
| ABLE 1.1. | |

| Botanical Name | Common Name | Edible Plant Part |
|---|--|---|
| Alpinia galanga (L.) Sw. | Greater galangal | Floral sprout and flower, tender shoot, rhizome |
| Curcuma longa L. Curcuma zedoaria (Christm.) Roscoe | Turmeric Long zedoary | Rhizome Rhizome |
| Zingiber mioga (Thunb.) Roscoe | Japanese wild ginger | Rhizome, tender shoot, leaf, flower |
| Zingiber officinale Roscoe | Ginger | Rhizome and tender shoot |
| Division Anthophyta Class Diocotyledons | | |
| Acanthaceae | ACANTHUS FAMILY | |
| Justicia insularis T. And. | Tettu | Young shoot, leaf, root |
| Rungia klossii S. Moore | Rungia | Leaf |
| $Mesembryanthemum\ crystallinum\ { m L}.$ | Ice plant | Leaf |
| Tetragonia tetragoniodes (Pall.) O. Kuntze Amaranthaceae | New Zealand spinach AMARANTH FAMILY | Tender shoot and leaf |
| Alternanthera philoxeroides (Martius) Griseb. Alternanthera sessilis (L.) R. Br. | Alligator weed, Joseph's coat Sessile alternanthera | Young top Young top |

| Amaranthus spp. | Amaranthus, tampala | Tender shoot, leaf, sprouted seed |
|---|--------------------------------|--------------------------------------|
| Celosia spp. Apiaceae | Cockscomb CARROT FAMILY | Leaf and tender shoot |
| Angelica archangelica L. | Angelica | Tender shoot and leaf |
| Angelica keiskei (Miq.) Koidz. | Japanese angelica | Tender shoot and leaf |
| Anthriscus cerefolium (L.) Hoffm. | Chervil | Leaf |
| Apium graveolens L. var. dulce (Mill.) Pers. | Celery | Petiole, leaf |
| Apium graveolens L. var. rapaceum (Mill.) Gaud. | Celeriac, turnip-rooted celery | Root, leaf |
| Arracacia xanthorrhiza Bancroft | Arracacha, Peruvian carrot | Root |
| Centella asiatica (L.) Urban | Asiatic pennywort | Leaf and stolon |
| Chaerophyllum bulbosum L. | Tuberous chervil | Root |
| Coriandrum sativum L. | Coriander | Leaf and seed |
| Cryptotaenia japonica Hassk. | Japanese hornwort | Leaf |
| Daucus carota L. subsp. sativus (Hoffm.) Arcang. | Carrot | Root and leaf |
| Foeniculum vulgare var. azoricum (Miller) Thell. | Fennel | Leaf |
| Foeniculum vulgare var. dulce Fiori | Florence fennel | Leaf base |
| Glehnia littoralis F. Schm. | Coastal glehnia | Leaf, stem, root |
| Hydrocotyle sibthorpioides Lam. | Hydrocotyle | Young shoot and leaf |
| Myrrhis odorata (L.) Scop. | Garden myrrh | Leaf, root, and seed |
| Oenanthe javanica (Blume) DC. subsp. javanica | Oriental celery, water | Leaf and tender shoot |
| | $\operatorname{dropwort}$ | |
| Pastinaca sativa L. | Parsnip | Root and leaf |
| Petroselinum crispum (Mill.) Nym. var. crispum | Parsley | Leaf |
| Petroselinum crispum (Mill.) Nym. tuberosum | Turnip-rooted parsley | Root and leaf |
| Petroselinum crispum (Mill.) Nym. var. neapolitanum | Italian parsley | Leaf |
| Sium sisarum L. | Skirret | Root |
| Araliaceae | AKALIA FAMILY | |
| Aralia cordata Thunb. | Spikenard | Tender shoot |

TABLE 1.1. BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS VEGETABLES (Continued)

| Botanical Name | Common Name | Edible Plant Part |
|--|----------------------------|-----------------------|
| Aralia elata Seeman Asteraceae | Japanese aralia | Young leaf |
| Arctium lappa L. | Edible burdock | Root, petiole |
| Artemisia dracunculus L. var. sativa L. Artemisia indica Willd. var. maximomiczii (Nakai) | French tarragon Muswort | Leaf Leaf |
| Hara | | |
| Aster scaber Thunb. | Aster | Leaf |
| Bidens pilosa L. | Bur marigold | Young shoot and leaf |
| Chrysanthemum spp. | Edible chrysanthemum | Leaf and tender shoot |
| Cichorium endivia L. | Endive, escarole | Leaf |
| Cichorium intybus L. | Chicory, withoof chicory | Leaf |
| Cirsium dipsacolepis (Maxim.) Matsum. | Gobouazami | Root |
| Cosmos caudatus Kunth | Cosmos | Leaf and young shoot |
| Crassocephalum biafrae (Oliv. et Hiern) S. Moore | Sierra Leone bologni | Young shoot and leaf |
| Crassocephalum crepidiodes (Benth.) S. Moore | Hawksbeard velvetplant | Young shoot and leaf |
| Cynara cardunculus L. | Cardoon | Petiole |
| Cynara scolymus L. | Globe artichoke | Immature flower bud |
| Emilia sonchifolia (L.) DC. | Emilia, false sow thistle | Young shoot and leaf |
| Enydra fluctuans Lour. | Buffalo spinach | Young shoot and leaf |
| Farfugium japonicum (L.) Kitamura | Japanese farfugium | Petiole |
| Fedia cornucopiae DC. | Horn of plenty, African | Leaf |
| | valerian | |

| artichoke uce | | ettuce, leaf lettuce ce | Butterbur Yacon strawberry Root | | Spotted garden thistle Leaf | sow thistle | | ca Young leaf | ng Young leaf and flower shoot | Noung leaf and flower shoot | Bitter leaf Young shoot Dandelion Leaf, root | Salsify, vegetable oyster Root and young leaf Goatsbeard, meadow salsify Young root and shoot Bitter leaf Young shoot |
|---|--|---|---|------------------------|-----------------------------|---|--|------------------------|------------------------------------|-----------------------------------|---|---|
| Galinsoga Gynura Jerusalem Indian lett | Aspaı Head lett | Roma Wild | Butte Yacor | Golde | Spott | Diack Milk | Brazi | Guasca | Getang | Getang | Bitte: Dand | Salsif Goats Bitter |
| Galinsoga parviflora Cav. Gynura bicolor DC. Helianthus tuberosus L. Lactuca indica L. | Lactuca sativa L. var. asparagina Bailey Lactuca sativa L. var. capitata L. | Lactuca sativa L. var. longifolia Lam. Launaea taraxacifolia (Willd.) Amin ex C. Jeffrey | Petasites japonicus (Sieb. & Zucc.) Maxim. Polymnia sonchifolia Poepp. & Endl. | Scolymus hispanicus L. | Scolymus maculatus L. | Scorzonera nispanica E. Sonchus oleraceus L. | $Spilanthes\ acmella\ ({ m L.})\ { m Murr.}$ | Spilanthes ciliata HBK | Spilanthes iabadicensus A.H. Moore | Spilanthes paniculata Wall ex DC. | Struchium spanganophora (L.) O. Ktze. Taraxacum officinale Wiggers | Tragopogon porrifolius L. Tragopogon pratensis L. Vernonia amygdalina Delile. |

| TABLE 1.1. | TABLE 1.1. BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS |
|------------|--|
| | VEGETABLES (Continued) |

| Botanical Name | Common Name | Edible Plant Part |
|--|------------------------------------|-----------------------|
| : | | |
| Basella alba L. | Indian spinach, Malabar spinach | Leaf and young shoot |
| Ullucus tuberosus Lozano | Ulluco | Tuber |
| Boraginaceae | BORAGE FAMILY | |
| Borago officinalis L. | Borage | Petiole |
| Symphytum officinale L. | Common comfrey | Leaf and tender shoot |
| $Symphytum 	imes uplandicum 	ext{ Nyman}$ | Russian comfrey | Young leaf and shoot |
| Brassicaceae | MUSTARD FAMILY | |
| Armoracia rusticana Gaertn., Mey., Scherb. | Horseradish | Root, leaf, sprouted |
| | | seed |
| Barbarea verna (Mill.) Aschers | Upland cress | Leaf |
| Brassica carinata A. Braun | Abyssinian mustard | Leaf |
| Brassica juncea (L.) Czernj. & Coss. var. capitata Hort. | Capitata mustard | Leaf |
| Brassica juncea (L.) Czernj. & Coss. var. crassicaulus Chen and Yang | Bamboo shoot mustard | Stem |
| Brassica juncea (L.) Czernj. & Coss. var. crispifolia Bailey | Curled mustard | Leaf |
| Brassica juncea (L.) Czernj. & Coss. var. foliosa Bailey | Small-leaf mustard | Leaf |
| Brassica juncea (L.) Czernj. & Coss. var. gemmifera Lee & Lin | Gemmiferous mustard | Stem and axillary bud |

| Leaf | Leaf | Leaf | Leaf | Leaf | Root | Leaf | Leaf | Leaf | Stem | Stem and leaf | Young flower stalk Root and leaf Leaf and young | Leaf Leaf Leaf |
|---|---|---|--|--|--|---|--|--|--|--|---|---|
| Involute mustard | Wide-petiole mustard | White-flowered mustard | Line mustard | Long-petiole mustard | Tuberous-rooted mustard | Tillered mustard | Flowerlike leaf mustard | Brown mustard, mustard greens | Strumous mustard | Swollen-stem mustard | Penduncled mustard Rutabaga Vegetable rape | Siberian kale, Hanover salad Black mustard Kale, collards |
| Brassica juncea (L.) Czernj. & Coss. var. involuta Yang & Chen | Brassica juncea (L.) Czernj. & Coss. var. latipa Li | Brassica juncea (L.) Czernj. & Coss. var. leucanthus Chen & Yang | Brassica juncea (L.) Czernj. & Coss. var. linearifolia | Brassica juncea (L.) Czernj. & Coss. var. longepetiolata Yang & Chen | Brassica juncea (L.) Czernj. & Coss. var. megarrhiza Tsen & Lee | Brassica juncea (L.) Czernj. & Coss. var. multiceps Tsen & Lee | Brassica juncea (L.) Czernj. & Coss. var. multisecta Bailey | Brassica juncea (L.) Czernj. & Coss. var. rugosa Bailey | Brassica juncea (L.) Czernj. & Coss. var. strumata Tsen & Lee | Brassica juncea (L.) Czernj. & Coss. var. tumida Tsen & Lee | Brassica juncea (L.) Czernj. & Coss. var. utilis Li Brassica napus L. var. napobrassica (L.) Reichb. Brassica napus L. var. napus | Brassica napus L. var. pabularia (DC.) Reichb. Brassica nigra L. Koch. Brassica oleracea L. var. acephala DC. |

| TABLE 1.1. | . BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS |
|------------|---|
| | VECETABLES (Continued) |

| Botanical Name | Common Name | Edible Plant Part |
|---|---------------------------|-----------------------|
| Brassica oleracea L. var. alboglabra Bailey | Chinese kale | Young flower stalk |
| • | | and leaf |
| Brassica oleracea L. var. botrytis L. | Cauliflower | Immature floral stalk |
| Brassica oleracea L. var. capitata L. | Cabbage | Leaf |
| Brassica oleracea L. var. costata DC. | Portuguese cabbage, | Leaf and |
| | tronchuda cabbage | inflorescence |
| Brassica oleracea L. var. gemmifera Zenk. | Brussels sprouts | Axillary bud |
| Brassica oleracea L. var. gongylodes L. | Kohlrabi | Enlarged stem |
| Brassica oleracea L. var. italica Plenck. | Broccoli | Immature flower |
| | | stalk |
| Brassica oleracea L. var. medullosa Thell. Marrow | Marrow stem kale | Leaf |
| Brassica oleracea L. var. ramosa Alef. | Thousand-headed kale | Leaf |
| Brassica oleracea L. var. sabauda L. | Savoy cabbage | Leaf |
| Brassica perviridis Bailey | Spinach mustard, | Leaf |
| | tendergreen mustard | |
| Brassica rapa L. var. chinensis (Rupr.) Olsson | Pak choi, Chinese mustard | Leaf |
| Brassica rapa L. var. narinosa (Bailey) Olsson | Broad-beaked mustard | Leaf |
| Brassica rapa L. var. parachinensis (Bailey) Tsen & Lee | Mock pak choi, choy sum | Leaf |
| Brassica rapa L. var. pekinensis (Lour.) Olsson | Chinese cabbage, pe-tsai | Leaf |
| Brassica rapa L. var. (DC.) Metzg. rapa | Turnip | Enlarged root |
| Brassica rapa L. var. (DC.) Metzg. utilis | Turnip green | Leaf |

| i raab Infloresence Leaf Young leaf | Petiole and young leaf | Petiole and young leaf, root | Leaf | Leaf | Root | Leaf | Leaf | Immature seed pod | Root | Root | Leaf and young | flower stalk | Rhizome, young shoot | | | Young leaf | | Pad, fruit | Y | Root and first leaf | | Flower bud | Leaf, young shoot, | fruit |
|---|------------------------|------------------------------|-----------------------------|-----------------------|------------------------|---------------------|------------------------------|------------------------------------|------------------------------------|----------------------------------|-----------------|--------------|---------------------------------|-------------|-------------------|---------------------------|---------------|---------------------------------|-------------------|-------------------------|--------------|---------------------|--------------------|-------|
| Turnip broccoli, broccoli raab Hill mustard Shepherd's purse | Sea kale | Tartar breadplant | Wallrocket | Rocket salad, arugula | Maca | Garden cress | Watercress | Rat-tail radish | Radish | Daikon | White mustard | | Wasabi, Japanese | horseradish | WATER LILY FAMILY | Watershield | CACTUS FAMILY | Prickly pear | BELLFLOWER FAMILY | Rampion | CAPER FAMILY | Capper | Cat's whiskers | |
| Brassica rapa L. var. (DC.) Metzg. septiceps Bunias orientalis L. Capasella bursa-pastoris (L.) Medikus | Crambe maritima L. | Crambe tatarica Jacq. | Diplotaxis muralis (L.) DC. | Eruca sativa Miller | Lepidium meyenni Walp. | Lepidium sativum L. | Nasturtium officinale R. Br. | Raphanus sativus L. Caudatus group | Raphanus sativus L. Radicula group | Raphanus sativus L. Daikon group | Sinapis alba L. | | Wasabia japonica (Miq.) Matsum. | | Cabombaceae | Brasenia schreberi Gmelin | Cactaceae | Opuntia ficus-indica (L.) Mill. | Campanulaceae | Campanula rapunculus L. | Capparaceae | Capparis spinosa L. | Cleome gynandra L. | |

TABLE 1.1. BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS VEGETABLES (Continued)

| Botanical Name | Common Name | Edible Plant Part |
|---|--|-----------------------|
| Platycodon grandiflorum A. DC. Chenopodiaceae | Chinese bellflower GOOSEFOOT FAMILY | Leaf |
| Atriplex hortensis L. | Orach | Leaf |
| Beta vulgaris L. Cicla group Beta vulgaris L. Crassa group | Chard, Swiss chard Garden beet | Leat Root and leaf |
| Chenopodium bonus-henricus L. | Good King Henry | Leaf |
| Chenopodium quinoa Willd. | Quinoa | Leaf |
| Kochia scoparia (L.) Schrader | Mock cypress | Tender shoot |
| Salsola komarovii Iljin. | Komarov Russian thistle | Leaf and young shoot |
| $Salsola\ soda\ L.$ | Salsola | Leaf and young shoot |
| Spinacia oleracea L. | Spinach | Leaf |
| Suaeda asparagoides Mak. | Common seepweed | Young stem, leaf, |
| | | plant |
| Convolvulaceae | BINDWEED FAMILY | |
| $Convolvulus\ japonicus\ { m Thumb.}$ | Rose glorybind | Root |
| $Ipomoea\ aquatica\ { m Forssk}.$ | Water spinach, kangkong | Tender shoot and leaf |
| $Ipomoea\ batatas\ (L.)\ Lam.$ | Sweet potato | Root and leaf |
| Crassulaceae | ORPINE FAMILY | |
| Sedum sarmentosum Burge | Sedum | Leaf |
| Cucurbitaceae | GOURD FAMILY | |
| Benincasa hispida (Thunb.) Cogn. | Wax gourd | Immature/mature |
| | | fruit |

| Citrullus lanatus (Thunb.) Matsum & Nakai Citrullus lanatus var. citroides (Bailey) Mansf. Coccinia grandis (L.) Voigt | Watermelon Citron, preserving melon Ivy gourd, tindora | Ripe fruit and seed Fruit Fruit, tender shoot, |
|--|--|--|
| Cucumeropsis mannii Naudin | White-seeded melon | Fruit and seed |
| Cucumis anguria L. | West Indian gherkin | Immature fruit |
| Cucumis melo L. Cantaloupensis group | Cantaloupe | Fruit |
| Cucumis melo L. Chito group | Mango | Fruit |
| Cucumis melo L. Conomon group | Oriental pickling melon | Young fruit |
| Cucumis melo L. Flexuosus group | Japanese cucumber, snake | Immature fruit |
| | melon | |
| Cucumis melo L. Inodorus group | Honeydew melon, casaba | Fruit |
| | melon | |
| Cucumis melo L. Reticulatus group | Muskmelon (cantaloupe), | Ripe fruit |
| | Persian melon | |
| Cucumis metuliferus E. Meyer ex Naudin | African horned cucumber | Fruit |
| Cucumis sativus L. | Cucumber | Immature fruit |
| Cucurbita argyrosperma Huber | Pumpkin | Young/mature fruit |
| | | and seed |
| Cucurbita ficifolia Bouché | Fig-leaf gourd, Malabar | Fruit |
| | gourd | |
| Cucurbita maxima Duchesne | Giant pumpkin, winter | Mature fruit and seed |
| | sduasn | |
| Cucurbita moschata Duchesne | Butternut squash, tropical | Young and mature |
| | pumpkin | fruit |
| Cucurbita pepo L. | Summer squash, zucchini | Young fruit |
| Cucurbita pepo L. | Common field pumpkin | Mature fruit and seed |
| Cyclanthera pedata (L.) Schrader var. pedata | Pepino | Immature fruit |

| TABLE 1.1. | TABLE 1.1. BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS |
|------------|--|
| | VEGETABLES (Continued) |

| Botanical Name | Common Name | Edible Plant Part |
|--|--|---|
| Lagenaria siceraria (Mol.) Standl. | Bottle gourd, calabash gourd | Immature fruit, tender shoot, and |
| Luffa acutangula (L.) Roxb. Luffa aegyptiaca Miller | Angled loofah Smooth loofah, sponge gourd | Immature fruit Immature fruit and |
| Momordica charantia L. | Bitter gourd, balsam pear | Immature fruit and |
| Praecitrullus fistulosus (Stocks) Pang. Sechium edule (Jacq.) Swartz. | Squash melon Chayote, mirliton, vegetable | Fruit Fruit, tender shoot, $\frac{1}{1-\epsilon}$ |
| Sicana odorifera (Vell.) Naudin | pear Casabanana | Immature/mature |
| Telfairia occidentalis Hook. f. | Fluted gourd, fluted pumpkin | Seed, leaf, tender |
| Telfairia pedata (Smith ex Sims) Hook. Trichosanthes cucumerina L. var. anguinea (L.) | Oyster nut Snake gourd | Seed Immature fruit, leaf, |
| riannes Trichosanthes cucumeroids (Ser.) Maxim. Trichosanthes dioica Roxb. | Japanese snake gourd Pointed gourd | and tender shoot Immature fruit Immature fruit, |
| Euphorbiaceae | SPURGE FAMILY | ${ m tender} \ { m shoot}$ |

| Cnidoscolus aconitifolius (Miller) Johnston Cnidoscolus chayamansa Mc Vaughn Codiaeum variegatum (L.) Blume Manihot esculenta Crantz Sauropus androgynus (L.) Merr. | Chaya Chaya Croton Yuca, cassava, manioc Common sauropus | Leaf Leaf Young leaf Root and leaf Leaf |
|---|--|---|
| Fabaceae | PEA FAMILY | |
| Arachis hypogaea L. | Peanut, groundnut | Immature/mature |
| Bauhinia esculenta Burchell | Marama bean | Immature pod and |
| | | root |
| Cajanus cajan (L.) Huth. | Cajan pea, pigeon pea | Immature pod/leaf |
| Canavalia ensiformis (L.) DC. | Jack bean, horse bean | Immature seed |
| Canavalia gladiata (Jacq.) DC. | Sword bean, horse bean | Immature seed |
| Cicer arietinum L. | Garbanzo, chickpea | Seed |
| Cyamposis tetragonoloba (L.) Taub. | Cluster bean, guar | Immature pod and |
| | | seed |
| Flemingia vestita Benth. ex Bak. | Flemingia | Tuber |
| Glycine max (L.) Merr. | Soybean | Immature and |
| | | sprouted seed |
| Lablab purpurus (L.) Sweet. | Hyacinth bean | Immature seed |
| Lathyrus sativus L. | Chickling pea | Immature pod/seed |
| Lathyrus tuberosus L. | Groundnut | Tuber |
| Lens culinaris Medikus | Lentil | Immature pod, |
| | | sprouted seed |
| $Lupinus 	ext{ spp.}$ | Lupin | Seed |
| Macrotyloma geocarpum (Harms) Marechal and Bandet. | Hausa groundnut | Seed |
| Macrotyloma uniflorum (Lam.) Verdc. | Horse gram | Seed |

TABLE 1.1. BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS VEGETABLES (Continued)

| Botanical Name | Common Name | Edible Plant Part |
|--|--|---|
| Medicago sativa L. | Alfalfa, lucerne | Leaf, young shoot, |
| Mucuna pruriens (L.) DC. | Buffalo bean, velvet bean | Seed |
| Neptunia oleracea Lour. | Water mimosa | Leaf and tender shoot |
| Pachyrhizus ahipa (Wedd.) Parodi | Yam bean | Root |
| Pachyrhizus erosus (L.) Urban | Jicama, Mexican yam bean | Root, immature pod, and seed |
| Pachyrhizus tuberosus (Lam.) Sprengel | Potato bean | Root and immature pod |
| Phaseolus acutifolius A. Gray | Tepary bean | Seed, immature pod |
| Phaseolus coccineus L. | Scarlet runner bean | Immature pod and |
| Phasoolus lunatus I. | Lima haan | Immature seed |
| Treascottes terretes Li | Linia Scan | mature seed |
| Phaseolus vulgaris L. | Garden bean, snap bean | Immature pod and seed |
| Pisum sativum L. ssp. sativum | Pea, garden pea | Immature seed, tender shoot |
| Pisum sativum L. ssp. sativum f. macrocarpon Psophocarpus tetragonolobus (L.) DC. | Snow pea, edible-podded pea Goa bean, winged bean | Immature pod Immature pod, seed, leaf, root |
| | | |

| Pueraria lobata (Willd.) Ohwi | Kudzu | Root, leaf, tender |
|---|--------------------------------------|---------------------|
| Sphenostylis stenocarpa (Hochst. ex. A. Rich.) Harms. | African yam bean | Tuber and seed |
| Tetragonolobus purpureus Moench | Asparagus pea, winged pea | Immature pod |
| Trigonella foenum-graecum L. | Fenugreek | Leaf, tender shoot, |
| | | immature pod |
| Vicia faba L. | Fava bean, broad bean, horse bean | Immature seed |
| Vigna aconitifolia (Jacq.) Maréchal | Moth bean | Immature pod and |
| Vigna angularis (Willd.) Ohwi & Ohashi | Adzuki bean | Seed |
| Vigna mungo (L.) Hepper | Black gram, urd | Immature pod and |
| | | seed |
| Vigna radiata (L.) Wilcz. | Mung bean | Immature pod, |
| | | sprouted seed, seed |
| Vigna subterranea (L.) Verdn. | Madagascar groundnut | Immature/mature |
| | | seed |
| Vigna umbellata (Thunb.) Ohwi & Ohashi | Rice bean | Seed |
| Vigna unguiculata (L.) Walp. subsp. cylindrica (L.) | Catjang | Immature pod and |
| Van Eselt, ex Verdn. | | seed |
| Vigna unguiculata (L.) Walp. subsp. sesquipedalis | Asparagus bean, yard-long | Immature pod and |
| (L.) | bean | seed |
| Vigna unguiculata (L.) Walp. subsp. unguiculata (L.) | Southern pea, cowpea | Immature pod and |
| | | seed |
| Gnetaceae | GNETUM FAMILY | |
| Gnetum gnemon L. | Bucko | Leaf, tender shoot |
| Haloragaceae | WATER MILFOIL FAMILY | |

| TABLE 1.1. | TABLE 1.1. BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS |
|------------|--|
| | VEGETABLES (Continued) |

| Common Name Edible Plant Part | Parrot's feather ICACINA FAMILY False yam MINT FAMILY Shiny bugleweed Pennyroyal mint Spearmint Common basil, sweet basil Hoary basil Marjoram Flowering plant and inflorescence Perilla Kaffir potato Savory, summer savory Hausa potato Japanese artichoke, Chinese ICACINA Tuber Leaf and seed Index Inde | MALLOW FAMILY Okra, gumbo Hibisens noot |
|-------------------------------|--|---|
| Botanical Name | Myriophyllum aquaticum (Vellozo) Verdc. Icacinaceae Icacina senegalensis A. Juss. Lamiaceae Lycopus lucidus Turcz. Mentha pulegium L. Mentha spicata L. em. Harley Ocimum basilicum L. Ocimum canum Sims. Origanum vulgare L. Perilla frutescens (L.) Britt. var. crispa (Thunb.) Deane Plectranthus esculentus N.E. Br. Satureja hortensis L. Solenostemon rotundifolius (Poir.) J. K. Morton Stackys affinis Bunge | $Malvaceae$ $Abelmoschus\ esculentus\ (L.)\ Moench$ |

| Hibiscus acetosella Wel. ex Hiern Hibiscus sabdariffa L. | False roselle Jamaican sorrel | Young leaf and shoot Calvx and leaf |
|---|----------------------------------|--|
| Malva rotundifolia L. | Mallow | Leaf and young shoot |
| Moraceae | MULBERRY FAMILY | |
| $Humulus\ lupulus\ L.$ | Hops | Tender shoot |
| Nelumbonaceae | LOTUS FAMILY | |
| Nelumbo nucifera Gaertn. | Lotus root | Rhizome, leaf, seed Seed |
| Nyctaginaceae | FOUR O'CLOCK FAMILY | |
| Mirabilis expansa (Ruiz & Paron) Standley | Mauka | Tuber |
| Nymphaeaceae | WATER LILY FAMILY | |
| Euryale ferox Salisb. | Foxnut | Seed, tender shoot, |
| | | root |
| Nymphaea nouchali Burm. f. | Water lily | Rhizome, flower stalk, |
| | | seed |
| Onagraceae | EVENING PRIMROSE | |
| | FAMILY | |
| Oenothera biennis L. | Evening primrose | Leaf and tender shoot |
| Orobanchaceae | BROOMRAPE FAMILY | |
| Orobanche crenata Forsskal. | Broomrape | Shoot |
| Oxalidaceae | OXALIS FAMILY | |
| Oxalis tuberosa Molina | Oka, oca | Tuber |
| Passifloraceae | PASSION FLOWER FAMILY | |
| Passiftora biftora Lam. | Passion flower | Shoot, young leaf, flower |
| Pedaliaceae | PEDALIUM FAMILY | |
| Sesamum radiatum Schum. ex Thonn. Phytolaccaceae | Gogoro POKEWEED FAMILY | Young shoot |

TABLE 1.1. BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS VEGETABLES (Continued)

| Botanical Name | Common Name | Edible Plant Part |
|--|---------------------------|----------------------|
| | | |
| Phytolacca acinosa Roxb. | Indian poke | Leaf and young shoot |
| Phytolacca americana L. | Poke | Leaf and young shoot |
| Phytolacca esculenta Van Houtte | Pokeweed | Leaf and young shoot |
| Phytolacca octandra L. | Inkweed | Leaf and young shoot |
| Plantaginaceae | PLAINTAIN FAMILY | |
| Plantago coronopus L. var. sativa Fiori | Buckshorn plantain | Leaf |
| Polygonaceae | BUCKWHEAT FAMILY | |
| Rheum rhabarbarum L. | Rhubarb, pieplant | Petiole |
| Rumex acetosa L. | Sorrel | Leaf |
| Rumex patientia L. | Dock | Leaf |
| Rumex scutatus L. | French sorrel | Leaf |
| Portulacaceae | PURSLANE FAMILY | |
| Montia perfoliata (Donn. ex Willd.) Howell | Winter purslane, miner's | Leaf |
| | lettuce | |
| Portulaca oleracea L. | Purslane | Leaf and young shoot |
| Talinum paniculatum (Jacq.) Gaertn. | Flameflower | Young shoot |
| Talinum triangulare (Jacq.) Willd. | Waterleaf, Suraim spinach | Leaf |
| Resedaceae | MIGNONETTE FAMILY | |
| Reseda odorata L. | Mignonette | Leaf and flower |
| Rosaceae | ROSE FAMILY | |
| Fragaria \times Ananassa Duchesne. | Strawberry | Fruit |
| Saururaceae | LIZARD'S-TAIL FAMILY | |
| Houttuynia cordata Thunb. | Saururis, tsi | Leaf |
| | | |

| Solanaceae | NIGHTSHADE FAMILY | |
|--|------------------------------|---------------------|
| Capsicum annuum L. Grossum group | Bell pepper | Fruit |
| Capsicum annuum L. Longum group | Cayenne pepper, chile pepper | Mature fruit |
| Capsicum baccatum L. var. baccatum | Small pepper | Fruit |
| Capsicum chinense Jacq. | Scotch bonnet pepper, | Fruit |
| | habanero pepper | |
| Capsicum frutescens L. | Tabasco pepper | Fruit |
| Capsicum pubescens Ruiz & Pavon | Rocoto | Fruit |
| Cyphomandra betacea (Cav.) Sendtner | Tamarillo, tree tomato | Ripe fruit |
| Lycium chinense Mill. | Boxthorn | Leaf |
| Lycopersicon esculentum Mill. | Tomato | Ripe fruit |
| Lycopersicon pimpinellifolium (L.) Mill. | Currant tomato | Ripe fruit |
| Physalis alkekengi L. | Chinese lantern plant | Ripe fruit |
| Physalis ixocarpa Brot. ex Hornem. | Tomatillo | Unripe fruit |
| Physalis peruviana L. | Cape gooseberry | Ripe fruit |
| Solanum aethiopicum L. | Golden apple | Fruit and leaf |
| Solanum americanum Mill. | American black nightshade | Tender shoot, leaf, |
| | | unripe fruit |
| Solanum gilo Raddi | Gilo, jilo | Young shoot |
| Solanum incanum L. | Garden egg | Unripe fruit |
| Solanum integrifolium Poir. | Scarlet eggplant, tomato | Immature fruit |
| | eggplant | |
| Solanum macrocarpon L. | African eggplant | Leaf and fruit |
| Solanum melongena L. | Eggplant, aubergine | Immature fruit |
| Solanum muricatum Ait. | Pepino, sweet pepino | Ripe fruit |
| Solanum nigrum L. | Black nightshade | Mature fruit, leaf, |
| | | tender shoot |
| Solanum quitoense Lam. | Naranjillo | Ripe fruit |
| Solanum torvum Swartz | Pea eggplant | Tender shoot, |
| | | immature fruit |

immature fruit

| TABLE 1.1. | TABLE 1.1. BOTANICAL NAMES, COMMON NAMES, AND EDIBLE PARTS OF PLANTS USED AS |
|------------|--|
| | VEGETABLES (Continued) |

| Botanical Name | Common Name | Edible Plant Part |
|--|---------------------|-----------------------|
| | | |
| Solanum tuberosum L. | Potato | Tuber |
| Tiliaceae | BASSWOOD FAMILY | |
| Corchorus olitorius L. | Jew's marrow | Leaf and tender shoot |
| Trapaceae | WATER CHESTNUT | |
| | FAMILY | |
| Trapa bicornis Osbeck | Water chestnut | Seed |
| Trapa natans L. | Water chestnut | Seed |
| Tropacolaceae | NASTURTIUM FAMILY | |
| Tropaeolum majus L. | Nasturtium | Leaf, flower |
| Tropaeolum tuberosum Ruiz & Pavon | Tuberous nasturtium | Tuber |
| Urticaceae | NETTLE FAMILY | |
| Pilea glaberrima (Blume) Blume | Pilea | Leaf |
| Pilea trinervia Wight | Pilea | Leaf |
| Urtica dioica L. | Stinging nettle | Leaf |
| Valerianaceae | VALERIAN FAMILY | |
| Valerianella eriocarpa Desv. | Italian corn-salad | Leaf |
| Valerianella locusta (L.) Laterrade em. Betcke | European corn-salad | Leaf |
| Violaceae | VIOLET FAMILY | |
| Viola tricolor L. | Violet, pansy | Flower, leaf |
| Vitaceae | GRAPE FAMILY | |
| Cissus javana DC. | Kangaroo vine | Leaf, young shoot |
| | | |

Adapted from S.J. Kays and J.C. Silva Dias, Cultivated Vegetables of the World (Athens, Ga.: Exon, 1996). Used with permission.

TABLE 1.2. NAMES OF COMMON VEGETABLES IN NINE LANGUAGES

| English | Danish | Dutch | French | German | Italian | Portuguese | Spanish | Swedish |
|---------------------|--------------|--------------|-------------|-----------------|------------|-------------|------------|---------------|
| | | | | | | | | |
| Artichoke | artiskok | artisjok | artischaut | Artischocke | carciofo | alcachofra | alcachofa | kronärtskocka |
| Asparagus | asparges | asperge | asperge | Spargel | asparago | espargo | espárrago | sparris |
| Broad bean | hestebønne | tuinboon | feve | Puffbohne | fava | fava | haba | bondböna |
| | | | | | maggiore | | | |
| Snap bean | bønne | poon | haricot | Bohne | fagiolino | feijão | judia | böna |
| Beet | rødbede | kroot | betterave | Rote Rübe | bietola da | beterraba | betabol | rödbeta |
| | | | rouge | | orta | de mesa | | |
| Broccoli | broccoli | broccoli | chou- | Brokkoli | cavolo | bróculo | bróculi | broccoli |
| | | | brocoli | | broccolo | | | |
| $\mathbf{Brussels}$ | rosenkål | spruitkool | chou de | Rosenkohl | cavolo di | couve de | col de | brysselkäl |
| sprouts | | | Bruxelles | | Bruxelles | Bruxelas | Bruselas | |
| Cabbage | kål | kool | chou | Kohl | cavolo | couve | col | käl |
| Carrot | karotte | been | carotte | Karotte | carota | cenoura | zanahoria | morot |
| Cauliflower | blomkål | bloemkool | chou-fleur | Blumenkohl | cavolfiore | courve-flor | coliflor | blomkål |
| Celery | selleri | selderij | céleri | Schnittselleri | sedano da | aipo | apio | selleri |
| | | | | | erbucci | | | |
| Celeriac | knoldselleri | knolselderij | céleri-rave | Knollensellerie | sedano | aipo de | apio nabo | rotselleri |
| | | | | | rapa | cabega | | |
| Chicory | cikorie | cichorei | chicoree | Zichorienwurzel | cicoria | chicoria do | achicoria | cikoria |
| | | | | | | café | de raiz | |
| Chinese | kinesisk kål | Chinese kool | chou de | Chinesischer | cavolo | couve da | col de | Salladkål |
| cabbage | | | Chine | Kohl | cinese | China | China | |
| Sweet corn | sukkermajs | suikermais | mais sucré | Zuckermais | mais dolce | milho doce | maiz dulce | sockermajs |

TABLE 1.2. NAMES OF COMMON VEGETABLES IN NINE LANGUAGES (Continued)

| English | Danish | Dutch | French | German | Italian | Portuguese | Spanish | ${\bf Swedish}$ |
|----------------------|------------|---------------|-----------|-------------|-------------|------------|-------------|-----------------|
| | | | | | | | | |
| Cucumber | agurk | komkommer | concombre | Gurke | cetriolino | pepino | pepino | gurka |
| Eggplant | aegplante | aubergine | aubergine | Aubergine | melanzana | beringela | berenjena | äggplanta |
| Endive | endivie | andijvie | chicorée | Endivie | indivia | chicoria | escarola | endiviesallat |
| | | | frisée | | | | | |
| Horseradish peberrod | peberrod | mierikswortel | raifort | Meerrettich | barbafonte | rabano | rábana | pepparrot |
| | | | | | | rústico | | |
| Kale | grønkål | boerekool | chou vert | Grunkohl | cavolo a | couve | berza | grönkål |
| | | | | | foglia | galega | enana | |
| | | | | | riccia | frizada | | |
| Kohlrabi | knudekål | koolrabi | chou-rave | Kohlrabi | cavolo-rapa | couve- | colirrábano | kålrabbi |
| | | | | | | rabano | | |
| Leek | porre | prei | poireau | Porree | porro | alho porro | puerro | purjolök |
| Lettuce | salat | sla | laitue | Salat | lattuga | alface | lechuga | sallad |
| Melon | melon | meloen | melon | Melone | popone | meläo | melón | melon |
| Onion | løg | in | ognon | Zwiebel | cipolla | cebola | cebolla | lök |
| Parsley | persille | peterselie | persil | Petersilie | prezzemola | salsa | perejil | persilja |
| | | | | | comune | frisada | | |
| Parsnip | pastinak | pastinaak | panais | Pastinake | pastinaca | pastinaca | chircivía | pasternacka |
| Pea | haveaert | erwt | pois | Erbse | pisello | ervilha | guisante | ärt |
| Pepper | peberfrugt | paprika | poivron | Paprika | peperone | pimento | pimentus | paprika |
| | | | | | dolce | | | |
| Potato | kartoffel | aardappel | pomme de | Kartoffel | patata | batata | patata | potatis |
| | | | terre | | | | | |

| Pumpkin | centnergraeskar | reuzenpompoen potiron | potiron | Zentnerkurbis | zucca gigante | abóbora | calabaza grande | jättepumpa |
|-------------|----------------------|-----------------------|------------|---------------|------------------|-----------|--------------------|-------------|
| | radis | radijs | radis | Radies | ravanello | rabanete | rábano | rädisa |
| | rabarber | rabarber | rhubarbe | Rhabarber | rabarbaro | ruibarbo | ruibarbo | rabarber |
| | kålrabi | koolraap | chou-navet | Kohlrübe | navone | rutabaga | colinabo | kälrot |
| | spinat | spinazie | épinard | Spinat | spinaci | espinafre | espinaca | spenat |
| | nyzeelandsk | Nieuwzeelandse | tetragone | Neuseelándsk | spinacio di | espinafre | espinaca | nyzeeländsk |
| Zealand | spinat | spinazie | | Spinat | Nuova | da Nova | Nueva | spenat |
| spinach | | | | | Zelanda | Zelândia | Zelandia | |
| Strawberry | jordbaer | aardbei | fraise | Erdbeere | fragola | morango | fresa | jordgubbe |
| | mandelgraeskavr | pompoen | citrouelle | Garten | zucca | abóbora | cababaza | matpumpa |
| squash | | | | | | porquiera | | |
| Swiss chard | bladbede | snijbiet | poirée | Mangold | bietola da | acelga | acelga | mangold |
| | | | | | costa | | | |
| | tomat | tomaat | tomate | Tomate | pomodoro | tomate | tomate | tomat |
| | majroe | meiraap | navet | Mairübe | rapa | nabo | nabo-colza | rova |
| | | | | | bianca | | | |
| lon | Watermelon vandmelon | watermeloen | melon | Wassermelone | melore | melancia | sandia | vattenmelon |
| | | | d'eau | | d'acqua | | | |

Adapted from P. J. with permission.

02 EDIBLE FLOWERS

TABLE 1.3. BOTANICAL NAMES, COMMON NAMES, FLOWER COLOR, AND TASTE OF SOME EDIBLE FLOWERS

Cautions:

- Proper identification of edible flowers is necessary.
 - Edible flowers should be pesticide free.
- Flowers of plants treated with fresh manure should not be used.
- Introduce new flowers into the diet slowly so possible allergic reactions can be identified.

| Botanical Name | Common Name | Flower Color | Taste |
|--|----------------------|--------------------------------|----------------------------|
| Agavaceae | CENTURY PLANT FAMILY | | |
| Yucca filamentosa L. | Yucca | Creamy white with purple tinge | Slightly bitter |
| Allicaceae | ONION FAMILY | | |
| Allium schoenoprasum L. | Chive | Lavender | Onion, strong |
| Allium tuberosum Rottl. ex. Sprengel Chinese chive | Chinese chive | White | Onion, strong |
| Tulbaghia violacea Harv. | Society garlic | Lilac | Onion |
| Apiaceae | CARROT FAMILY | | |
| Anethum graveolens L. | Dill | Yellow | Stronger than leaves |
| Anthriscus cerefolium (L.) Hoffm. | Chervil | White, pink, yellow, | Parsley |
| | | red, orange | |
| $Coriandrum\ sativum\ {\rm L}.$ | Coriander | White | Milder than leaf |
| Foeniculum vulgare Mill. | Fennel | Pale yellow | Licorice, milder than leaf |

| Asteraceae | SUNFLOWER FAMILY | | |
|---|------------------------|---------------------------------------|---------------------------|
| Bellis perennis L. | English daisy | White to purple petals Mild to bitter | Mild to bitter |
| Calendula officinalis L. | Calendula | Yellow, gold, orange | Tangy and peppery |
| Carthamus tinctorius L. | Safflower | Yellow to deep red | Bitter |
| Chamaemelum nobilis Mill. | English chamomile | White petals, yellow | Sweet apple |
| | | center | |
| Chrysanthemum coronarium L. | Garland chrysanthemum | Yellow to white | Mild |
| Chicorium intybus L. | Chicory | Blue to lavender | Similar to endive |
| Dendranthema $	imes$ grandifolium Kitam. | Chrysanthemum | Various | Strong to bitter |
| Leucanthemum vulgare Lam. | Oxeye daisy | White, yellow center | Mild |
| Tagetes erecta L. | African marigold | White, gold | Variable, mild to bitter |
| Tageto tenuifolia Cav. | Signet marigold | White, gold, yellow, | Citrus, milder than T . |
| | | $_{ m red}$ | erecta |
| Taraxicum officianle L. | Dandelion | Yellow | Bitter |
| Begonaiceae | BEGONIA FAMILY | | |
| Begonia tuberhybrida | Tuberous begonia | Various | Citrus |
| Boraginaceae | BORAGE FAMILY | | |
| $Borago\ officinalis\ { m L}.$ | Borage | Blue, purple, lavender Cucumber | Cucumber |
| Brassicaceae | MUSTARD FAMILY | | |
| Brassica spp. | Mustard | Yellow | Tangy to hot |
| Eruca vesicaria Mill. | Arugala | White | Nutty, smoky |
| Raphanus sativus L. | \mathbf{Radish} | White, pink | Spicy |
| Caryophyllaceae | PINK FAMILY | | |
| $Dianthus { m spp.}$ | Pinks | Pink, white, red | Spicy, cloves |
| Cucurbitaceae | GOURD FAMILY | | |
| Cucurbita pepo L. | Summer squash, pumpkin | Yellow | Mild, raw squash |

TABLE 1.3. BOTANICAL NAMES, COMMON NAMES, FLOWER COLOR, AND TASTE OF SOME EDIBLE FLOWERS (Continued)

| Botanical Name | Common Name | Flower Color | Taste |
|----------------------------------|-----------------------|-------------------------------|--------------------------|
| Fabaceae | PEA FAMILY | | |
| Cercis canadensis L. | Redbud | Pink | Bean-like to tart apple |
| Phaseolus coccineus L. | Scarlet runner bean | Bright orange to scarlet | Mild raw bean |
| Pisum sativum L. | Garden pea | White, tinged pink | Raw pea |
| Trifolium pretense L. | Red clover | Pink, lilac | Hay |
| Geraniaceae | GERANIUM FAMILY | | |
| Pelargonium spp. L'Hérit | Scented geraniums | White, red, pink, | Various, e.g., apple, |
| | | purple | lemon, rose, spice, etc. |
| Iridaceae | IRIS FAMILY | | |
| Gladiolus spp. L. | Gladiolus | Various | Mediocre |
| Lamiaceae | MINT FAMILY | | |
| $Hyssopus\ officinalis\ { m L}.$ | Hyssop | Blue, pink, white | Bitter, similar to tonic |
| Lavandula augustifolia Mill. | Lavender | Lavender, purple, | Highly perfumed |
| | | pink, white | |
| $Melissa\ officinalis\ { m L}.$ | Lemon balm | Creamy white | Lemony, sweet |
| Mentha spp. L. | Mint | Lavender, pink, white | Minty |
| Monarda didyma L. | Bee balm | Red, pink, white, lavender | Tea-like |
| Ocimum basilicum L. | Basil | White to pale pink | Spicy |
| Origanum vulgare L. | Oregano | White | Spicy, pungent |
| Origanum majorana L. | Marjoram | Pale pink | Spicy, sweet |

| Rosmarinus officinalis L. Salvia rutilans Carr. | Rosemary Pineapple sage | Blue, pink, white Scarlet | Mild rosemary Pineannle/sage |
|--|---------------------------------|-------------------------------|------------------------------------|
| | age of Japan | | overtones |
| Salvia officinalis L. | Sage | Blue, purple, white, pink | Flowery sage |
| Satureja hortensis L. | Summer savory | Pink | Mildly peppery, spicy |
| Satureja montana L. | Winter savory | Pale blue to purple | Mildly peppery, spicy |
| Thymus spp. L. Liliaceae | Thyme LILY FAMILY | Pink, purple, white | Milder than leaves |
| Hemerocallis fulva L. | Daylily | Tawny orange | Cooked asparagus/ zucchini |
| Muscari neglectum Guss. ex Ten | Grape hyacinth | Pink, blue | Grapey |
| Tulipa spp. L. Malvaceae | Tulip MALLOW FAMILY | Various | Slightly sweet or bitter |
| Abelmochus esculentus (L.) Moench. | Okra | Yellow, red | Mild, sweet, slightly mucilaginous |
| Alcea rosa L. | Hollyhock | Various | Slightly bitter |
| Hibiscus rosa-sinensis L. | Hibiscus | Orange, red, purple | Citrus, cranberry |
| Hibiscus syriacus L. | Rose of Sharon | Red, white, purple, violet | Mild, nutty |
| Myrtaceae | MYRTLE FAMILY | | |
| Acca sellowiara O. Berg Oleaceae | Pineapple guava OLIVE FAMILY | White to deep pink | Papaya or exotic melon |
| Syringa vulgaris L. | Lilac | White, pink, purple, lilac | Perfume, slightly bitter |
| Papaveraceae | POPPY FAMILY | | |
| Sanguisorba minor Soep. Rosacese | Burnet ROSE FAMILY | Red | Cucumber |
| | | | |

TABLE 1.3. BOTANICAL NAMES, COMMON NAMES, FLOWER COLOR, AND TASTE OF SOME EDIBLE FLOWERS (Continued)

| Botanical Name | Common Name | Flower Color | Taste |
|--------------------------------|-------------------|-----------------------|-------------------------|
| | | | |
| Malus spp. Mill. | Apple, crabapple | White to pink | Slightly floral to sour |
| Rubiaceae | MADDER FAMILY | | |
| Galium odoratum (L.) Scop. | Sweet woodruff | White | Sweet, grassy, vanilla |
| Rutaceae | RUE FAMILY | | |
| Citrus limon (L.) Burm. | Lemon | White | Citrus, slightly bitter |
| Citrus sinensis (L.) Osbeck. | Orange | White | Citrus, sweet/strong |
| Tropaeolaceae | NASTURTIUM FAMILY | | |
| $Tropaeolum\ majus\ { m L}.$ | Nasturtium | Variable | Watercress, peppery |
| Violaceae | VIOLET FAMILY | | |
| Viola odorata L. | Violet | Violet, pink, white | Sweet |
| Viola 	imes wittrockiana Gams. | Pansy | Various, multicolored | Stronger than violets |
| Viola tricolor L. | Johnny-jump-up | Violet, white, yellow | Stronger than violets |
| | | | |

Adapted from K.B. Badertsher and S.E. Newman, Edible Flowers (Colorado Cooperative Extension), http://www.ext.colostate.edu/pubs/garden/07237.html. Useful reference: Jeanne Mackin, Cornell Book of Herbs and Edible Flowers (Ithaca, N.Y.: Cornell Cooperative Extension).

03 U.S. VEGETABLE PRODUCTION

TABLE 1.4. U.S. VEGETABLE PRODUCTION STATISTICS: LEADING FRESH MARKET VEGETABLE STATES, 2004¹

| | Harvested A | Acreage | Product | ion | Value | e |
|----------|-------------|---------------|------------|---------------|------------|---------------|
| Rank | State | % of Total | State | % of Total | State | % of Total |
| 1 | California | 43.4 | California | 48.8 | California | 52.9 |
| 2 | Florida | 9.5 | Florida | 9.1 | Florida | 11.8 |
| 3 | Georgia | 7.0 | Arizona | 8.4 | Arizona | 8.7 |
| 4 | Arizona | 6.7 | Georgia | 4.5 | Georgia | 3.9 |
| 5 | New York | 4.0 | Texas | 3.7 | Texas | 3.5 |

¹Includes data for artichoke, asparagus, *lima bean, snap bean, broccoli, *Brussels sprouts, cabbage, carrot, cauliflower, *celery, cantaloupe, cucumber, eggplant, escarole/endive, garlic, honeydew melon, lettuce, onion, bell pepper, spinach, sweet corn, tomato, and watermelon.

^{*}Includes fresh market and processing.

TABLE 1.5. IMPORTANT STATES IN THE PRODUCTION OF U.S. FRESH MARKET VEGETABLES BY CROP VALUE, 2004

| Crop First | | Second | Third | |
|--------------------------|--------------|--------------|----------------|--|
| $Artichoke^1$ | California | _ | _ | |
| Asparagus ¹ | California | Washington | Michigan | |
| Bean, snap | Florida | California | Georgia | |
| $\mathrm{Broccoli^1}$ | California | Arizona | _ | |
| Cabbage | California | Texas | New York | |
| Cantaloupe | California | Arizona | Texas | |
| Carrot | California | Texas | Michigan | |
| Cauliflower ¹ | California | Arizona | New York | |
| Celery | California | Michigan | _ | |
| Cucumber | Florida | Georgia | California | |
| Garlic | California | Oregon | Nevada | |
| Honeydew melon | California | Arizona | Texas | |
| Lettuce, head | California | Arizona | Colorado | |
| Lettuce, leaf | California | Arizona | _ | |
| Lettuce, romaine | California | Arizona | _ | |
| $Mushroom^1$ | Pennsylvania | California | Florida | |
| Onion | California | Texas | Oregon | |
| Pepper, bell | California | Florida | New Jersey | |
| Pepper, chile | California | New Mexico | Texas | |
| Pumpkin | New York | Pennsylvania | California | |
| Spinach | California | Arizona | Texas | |
| Squash | California | Florida | New York | |
| Strawberry | California | Florida | North Carolina | |
| Sweet corn | California | Florida | New York | |
| Tomato | California | Florida | Texas | |
| Watermelon | California | Florida | Texas | |

¹Includes fresh market and processing.

TABLE 1.6. HARVESTED ACREAGE, PRODUCTION, AND VALUE OF U.S. FRESH MARKET VEGETABLES, 2002–2004 AVERAGE

| | | Production | Value |
|----------------------------|---------|------------|-----------|
| Crop | Acres | (1000 cwt) | (\$1000) |
| $Artichoke^1$ | 7,633 | 925 | 71,716 |
| Asparagus ¹ | 58,833 | 1,086 | 176,870 |
| Bean, snap | 94,733 | 5,840 | 277,141 |
| $\mathrm{Broccoli}^1$ | 133,300 | 19,520 | 119,995 |
| Cabbage | 75,460 | 23,967 | 316,398 |
| Cantaloupe | 88,583 | 21,608 | 356,867 |
| Carrot | 85,400 | 26,577 | 518,266 |
| Cauliflower ¹ | 40,533 | 6,612 | 218,110 |
| $Celery^1$ | 27,300 | 18,932 | 260,904 |
| Cucumber | 55,357 | 10,005 | 202,636 |
| $Garlic^1$ | 33,133 | 5,705 | 151,452 |
| Honeydew melon | 23,100 | 5,133 | 93,235 |
| Lettuce, head | 185,400 | 78,785 | 1,282,088 |
| Lettuce, leaf | 55,100 | 13,461 | 422,747 |
| Lettuce, romaine | 72,000 | 22,649 | 534,087 |
| Onion | 165,153 | 74,702 | 870,217 |
| Pepper, bell ¹ | 54,167 | 16,196 | 511,813 |
| Pepper, chile ¹ | 29,700 | 4,223 | 110,460 |
| Pumpkin ¹ | 41,657 | 8,878 | 90,867 |
| Spinach | 36,393 | 5,543 | 203,619 |
| Squash ¹ | 51,867 | 8,078 | 207,571 |
| Strawberry ¹ | 49,200 | 20,847 | 1,336,008 |
| Sweet corn | 246,243 | 28,031 | 559,580 |
| Tomato | 125,707 | 37,094 | 1,309,213 |
| Watermelon | 147,733 | 38,207 | 328,342 |

¹ Includes fresh market and processing.

TABLE 1.7. AVERAGE U.S. YIELDS OF FRESH MARKET VEGETABLES, 2002–2004

| Crop | Yield (cwt/acre) |
|----------------------------|------------------|
| $ m Artichoke^{1}$ | 122 |
| Asparagus ¹ | 31 |
| Bean, snap | 62 |
| Broccoli ¹ | 146 |
| Cabbage | 317 |
| Cantaloupe | 244 |
| Carrot | 311 |
| Cauliflower ¹ | 163 |
| Celery ¹ | 693 |
| Cucumber | 181 |
| Garlic ¹ | 172 |
| Honeydew melon | 223 |
| Lettuce, head | 371 |
| Lettuce, leaf | 244 |
| Lettuce, romaine | 315 |
| Onion | 452 |
| Pepper, bell ¹ | 299 |
| Pepper, chile ¹ | 142 |
| Pumpkin ¹ | 211 |
| Spinach | 152 |
| Squash ¹ | 156 |
| Strawberry ¹ | 423 |
| Sweet corn | 114 |
| Tomato | 295 |
| Watermelon | 259 |

¹Includes fresh market and processing.

TABLE 1.8. LEADING U.S. PROCESSING VEGETABLE STATES, 2004^1

| | Harvested Acreage | | creage Production | | Value | |
|------|-------------------|---------------|-------------------|---------------|------------|---------------|
| Rank | State | % of Total | State | % of Total | State | % of Total |
| 1 | California | 24.1 | California | 67.8 | California | 51.2 |
| 2 | Minnesota | 16.0 | Washington | 6.3 | Wisconsin | 7.0 |
| 3 | Wisconsin | 15.0 | Wisconsin | 5.7 | Minnesota | 6.9 |
| 4 | Washington | 11.0 | Minnesota | 5.7 | Washington | 6.8 |
| 5 | Oregon | 5.0 | Oregon | 2.4 | Michigan | 4.1 |

TABLE 1.9. HARVESTED ACREAGE, PRODUCTION, AND VALUE OF U.S. PROCESSING VEGETABLES, 2002–2004 AVERAGE

| Crop | Acres | Production (tons) | Value (\$1000) |
|------------|---------|-------------------|-------------------|
| Bean, lima | 46,267 | 59,757 | 25,854 |
| Bean, snap | 196,600 | 781,630 | 122,141 |
| Carrot | 15,770 | 426,300 | 32,081 |
| Cucumber | 116,700 | 616,907 | 168,149 |
| Pea, green | 215,833 | 402,540 | 101,186 |
| Spinach | 12,640 | 118,140 | 13,354 |
| Sweet corn | 416,500 | 3,100,640 | 217,495 |
| Tomato | 302,247 | 11,252,313 | 658,516 |

 $^{^{1}}$ Includes lima bean, snap bean, carrot, sweet corn, cucumber for pickles, pea, spinach, and tomato.

TABLE 1.10. IMPORTANT STATES IN THE PRODUCTION OF U.S. PROCESSING VEGETABLES BY CROP VALUE, 2004

| Crop | First | Second | Third |
|------------|------------|------------|----------------|
| Bean, snap | Wisconsin | Oregon | New York |
| Carrot | California | Washington | Wisconsin |
| Cucumber | Michigan | Florida | North Carolina |
| Pea, green | Minnesota | Washington | Wisconsin |
| Spinach | California | _ | _ |
| Sweet corn | Minnesota | Washington | Wisconsin |
| Tomato | California | Indiana | Ohio |

TABLE 1.11. AVERAGE U.S. YIELDS OF PROCESSING VEGETABLES, 2002–2004

| Crop | Yield (tons/acre) |
|------------|----------------------|
| Bean, lima | 1.29 |
| Bean, snap | 3.97 |
| Carrot | 27.02 |
| Cucumber | 5.07 |
| Pea, green | 1.86 |
| Spinach | 9.44 |
| Sweet corn | 7.44 |
| Tomato | 37.20 |

TABLE 1.12. U.S. POTATO AND SWEET POTATO PRODUCTION STATISTICS: HARVESTED ACREAGE, YIELD, PRODUCTION, AND VALUE, 2002–2004 AVERAGE

| Crop | Acres | Yield (cwt/acre) | Production (1000 cwt) | Value (\$1000) |
|--------------|-----------|---------------------|--------------------------|-------------------|
| Potato | 1,227,533 | 373 | 457,449 | 2,765,300 |
| Sweet Potato | 89,400 | 168 | 15,029 | 269,176 |

Adapted from Vegetables and Melons Outlook VGS-307 (USDA Economic Research Service, 2005), http://www.ers.usda.gov/publications/vgs/Feb05/vgs307.pdf.

TABLE 1.13. IMPORTANT U.S. STATES IN POTATO AND SWEET POTATO PRODUCTION BY CROP VALUE, 2003

| Rank | Potato | Sweet Potato |
|------|---------------------------|----------------|
| 1 | Idaho | North Carolina |
| 2 | Washington | California |
| 3 | California | Louisiana |
| 4 | Wisconsin | Mississippi |
| 5 | $\operatorname{Colorado}$ | Alabama |

 $\label{local-condition} A dapted from \textit{Vegetables and Melons Outlook VGS-307} \ (USDA \ Economic \ Research \ Service, 2005), \\ http://www.ers.usda.gov/publications/vgs/Feb05/vgs307.pdf.$

TABLE 1.14. UTILIZATION OF THE U.S. POTATO CROP, 2001–2003 AVERAGE

| | Amount | | |
|-----------------------------------|----------|------------|--|
| Item | 1000 cwt | % of Total | |
| A. Sales | 413,227 | 91 | |
| 1. Table stock | 129,936 | 29 | |
| 2. Processing | 256,808 | 57 | |
| a. Chips | 52,825 | 12 | |
| b. Dehydration | 46,845 | 10 | |
| c. Frozen french fries | 126,033 | 28 | |
| d. Other frozen products | 25,473 | 6 | |
| e. Canned potatoes | 4,651 | 1 | |
| f. Starch and flour | 981 | <1 | |
| 3. Other sales | 26,483 | 6 | |
| a. Livestock feed | 2,848 | <1 | |
| b. Seed | 23,634 | 5 | |
| B. Nonsales | 37,992 | 8 | |
| 1. Seed used on farms where grown | 5,516 | 1 | |
| 2. Shrinkage | 32,476 | 7 | |
| Total production | 451,219 | | |

 $\label{local-condition} A dapted from \textit{Vegetables and Melons Outlook VGS-307} \mbox{ (USDA Economic Research Service, 2005), http://www.ers.usda.gov/publications/vgs/Feb05/vgs307.pdf.}$

04 VEGETABLE CONSUMPTION

TABLE 1.15. TRENDS IN U.S. PER CAPITA CONSUMPTION OF VEGETABLES

Amount (lb)1

| Year | Fresh | Processed | Total |
|------|-------|-----------|-------|
| 1971 | 171 | 189 | 360 |
| 1975 | 180 | 187 | 367 |
| 1980 | 172 | 184 | 356 |
| 1985 | 187 | 198 | 385 |
| 1990 | 198 | 212 | 410 |
| 1995 | 210 | 223 | 433 |
| 2000 | 228 | 222 | 450 |
| 2004 | 227 | 219 | 446 |
| | | | |

 $\label{local-condition} A dapted from \textit{Vegetables and Melons Outlook VGS-307} \mbox{ (USDA Economic Research Service, 2005), http://www.ers.usda.gov/publications/vgs/Feb05/vgs307.pdf.}$

¹Fresh weight equivalent.

TABLE 1.16. U.S. PER CAPITA CONSUMPTION OF COMMERCIALLY PRODUCED VEGETABLES, 2004

Amount (lb)

| Vegetable | Fresh | Canned | Frozen | Total |
|--------------------------|-------|------------|--------|------------|
| Artichoke, all | _ | _ | _ | 0.7 |
| Asparagus | 1.1 | 0.2 | 0.10 | 1.4 |
| Bean, dry, all | _ | _ | _ | 6.7 |
| Bean, snap | 2.1 | 3.5 | 1.9 | 7.4 |
| Broccoli | 5.8 | _ | 2.4 | 8.2 |
| Cabbage | 7.9 | 1.1 | _ | 9.0 |
| Cantaloupe | 11.0 | _ | _ | 11.0 |
| Carrot | 8.4 | 1.5 | 1.7 | 11.5 |
| Cauliflower | 1.7 | _ | 0.5 | 2.2 |
| Celery | 6.2 | _ | _ | 6.2 |
| Cucumber | 6.3 | 4.9 | _ | 11.2 |
| Eggplant, all | _ | _ | _ | 0.7 |
| Escarole/endive | 0.2 | _ | _ | 0.3 |
| Garlic, all | _ | _ | _ | 2.8 |
| Honeydew melon | 2.2 | _ | _ | 2.2 |
| Lettuce, head | 21.3 | _ | _ | 21.3 |
| Lettuce, leaf & romaine | 10.0 | _ | _ | 10.0 |
| Mushroom, all | 2.6 | 1.6 | _ | 4.2 |
| Onion | 19.3 | _ | _ | 20.8^{1} |
| Pea, green | | 1.3 | 1.9 | 3.3 |
| Pea and lentil, dry, all | | _ | _ | 0.6 |
| Pepper, bell | 7.2 | _ | _ | 7.2 |
| Pepper, chile | _ | 5.7 | _ | 5.7 |
| Potato | 45.6 | 33.8^{2} | 56.6 | 136.0 |
| Spinach, all | | _ | _ | 1.8 |
| Strawberry | 5.4 | _ | 1.7 | 7.1 |
| Sweet corn ³ | 9.7 | 8.8 | 9.5 | 27.8 |
| Sweet potato, all | | _ | _ | 4.3 |
| Tomato | 19.1 | 69.8 | _ | 88.9 |
| Watermelon | 14.0 | _ | _ | 14.0 |
| Other vegetables, all | | | | 12.1 |

 $\label{local-condition} A dapted from \textit{Vegetables and Melons Outlook VGS-307} \mbox{ (USDA Economic Research Service, 2005), http://www.ers.usda.gov/publications/vgs/Feb05/vgs307.pdf.}$

¹ Includes fresh and dehydrated onion.

²Other processed potato.

³On-cob basis.

TABLE 1.17. TRENDS IN U.S. PER CAPITA CONSUMPTION OF POTATO, SWEET POTATO, DRY BEAN, AND DRY PEA

Amount (lb)

| Period | Potato ¹ | Sweet Potato ² | Dry Bean | Dry Pea |
|-------------------|---------------------|---------------------------|----------|---------|
| 1947–1949 average | 114 | 13 | 6.7 | 0.6 |
| 1957–1959 average | 107 | 8 | 7.7 | 0.6 |
| 1965 | 108 | 6 | 6.6 | 0.4 |
| 1970 | 118 | 6 | 5.9 | 0.3 |
| 1975 | 122 | 5 | 6.5 | 0.4 |
| 1980 | 116 | 5 | 5.4 | 0.4 |
| 1985 | 122 | 5 | 7.1 | 0.5 |
| 1990 | 128 | 5 | 6.4 | 0.5 |
| 1995 | 139 | 4 | 7.4 | 0.5 |
| 2000 | 139 | 4 | 7.6 | 0.9 |
| 2004 | 136 | 4 | 6.7 | 0.6 |

 $\label{lem:continuous} A dapted from \textit{Vegetable Outlook and Situation Report TVS-233} \ (1984); \textit{Vegetables and Specialties} \ \textit{TVS-260} \ (1993); \textit{Vegetables and Specialties} \ \textit{TVS-265} \ (1995); \text{ and } \textit{Vegetables and Melons Outlook VGS-307} \ (USDA Economic Research Service, 2005), \ http://www.ers.usda.gov/publications/vgs/Feb05/vgs307.pdf.$

 $^{^{\}rm 1} Includes$ fresh and processed potato.

² Includes fresh and processed sweet potato.

05 WORLD VEGETABLE PRODUCTION

TABLE 1.18. IMPORTANT VEGETABLE-PRODUCING COUNTRIES, 2004

| Crop | First | Second | Third |
|-------------------------|---------------|--------------------|--------------------|
| Artichoke | Italy | Spain | Argentina |
| Asparagus | China | Peru | United States |
| Bean, snap | United States | France | Mexico |
| Cabbage | China | India | Russian Federation |
| Cantaloupe | China | Turkey | United States |
| Carrot | China | United States | Russia |
| Cauliflower | China | India | Italy |
| Cucumber | China | Turkey | Iran |
| Eggplant | China | India | Turkey |
| Garlic | China | India | South Korea |
| Lettuce | China | United States | Spain |
| Mushroom | China | United States | Netherlands |
| Okra | India | Nigeria | Pakistan |
| Onion | China | India | United States |
| Pea, green | India | China | United States |
| Pepper | China | Mexico | Turkey |
| Potato | China | Russian Federation | India |
| Pumpkin | China | India | Ukraine |
| Spinach | China | United States | Japan |
| Strawberry ¹ | United States | Spain | Japan |
| Sweet corn | United States | Nigeria | France |
| Sweet potato | China | Uganda | Nigeria |
| Tomato | China | United States | Turkey |
| Watermelon | China | Turkey | Iran |
| All | China | India | United States |

 $\label{lem:condition} A dapted from \textit{Vegetables and Melons Situation and Outlook Yearbook VGS-2005} \ (USDA, Economic Research Service, 2005), http://www.ers.usda.gov/publications/vgs/JulyYearbook2005/VGS2005.pdf.$

 $^{^1} http://usda.mannlib.cornell.edu/data-sets/specialty/95003/.$

TABLE 1.19. WORLD VEGETABLE PRODUCTION, 2001–2003 AVERAGE

| Country | Production (million cwt) | (%) |
|--------------------|-----------------------------|-------|
| China | 8,988.1 | 48.9 |
| India | 1,697.3 | 9.2 |
| United States | 823.6 | 4.5 |
| Turkey | 552.5 | 3.0 |
| Russian Federation | 326.0 | 1.7 |
| Italy | 325.5 | 1.7 |
| Others | 5,622.5 | 31.0 |
| World | 18,351.3 | 100.0 |

 $\label{lem:condition} A dapted from \textit{Vegetables and Melons Situation and Outlook Yearbook VGS-2005} \ (USDA, Economic Research Service, 2005), http://www.ers.usda.gov/publications/vgs/JulyYearbook2005/VGS2005.pdf.$

06 NUTRITIONAL COMPOSITION

TABLE 1.20. COMPOSITION OF THE EDIBLE PORTIONS OF FRESH, RAW VEGETABLES

Amount/100 g Edible Portion

| | Water | Energy | Protein | Fat | Carbohydrate | Fiber | Ca | Д | Яe | Na | × |
|------------------|-------|--------|---------|-----|--------------|-------|------|------|------|------|------|
| Vegetable | (%) | (kcal) | (g) | (g) | , (g) | (g) | (mg) | (mg) | (mg) | (mg) | (mg) |
| Artichoke | 85 | 47 | 3.3 | 0.2 | 10.5 | 5.4 | 44 | 06 | 1.3 | 94 | 370 |
| Asparagus | 93 | 20 | 2.2 | 0.1 | 3.9 | 2.1 | 24 | 52 | 2.1 | 2 | 202 |
| Bean, green | 06 | 31 | 1.8 | 0.1 | 7.1 | 3.4 | 37 | 38 | 1.0 | 9 | 209 |
| Bean, lima | 20 | 113 | 8.9 | 6.0 | 20.2 | 4.9 | 34 | 136 | 3.1 | œ | 467 |
| Beet greens | 91 | 22 | 2.2 | 0.1 | 4.3 | 3.7 | 117 | 41 | 2.6 | 226 | 762 |
| Beet roots | 88 | 43 | 1.6 | 0.2 | 9.6 | 8.7 | 16 | 40 | 8.0 | 78 | 325 |
| Broccoli | 88 | 34 | 8.8 | 0.4 | 9.9 | 2.6 | 47 | 99 | 0.7 | 33 | 316 |
| Broccoli raab | 93 | 22 | 3.2 | 0.5 | 2.9 | 2.7 | 108 | 73 | 2.1 | 33 | 196 |
| Brussels sprouts | 98 | 43 | 3.4 | 0.3 | 9.0 | 3.8 | 42 | 69 | 1.4 | 25 | 389 |
| Cabbage, common | 92 | 24 | 1.4 | 0.1 | 5.6 | 2.3 | 47 | 23 | 9.0 | 18 | 246 |
| Cabbage, red | 90 | 31 | 1.4 | 9.0 | 7.4 | 2.1 | 45 | 30 | 8.0 | 27 | 243 |
| Cabbage, savoy | 91 | 27 | 2.0 | 0.1 | 6.1 | 3.1 | 35 | 45 | 0.4 | 28 | 230 |
| Carrot | 88 | 41 | 6.0 | 0.2 | 9.6 | 8.7 | 33 | 35 | 0.3 | 69 | 320 |
| Cauliflower | 92 | 25 | 2.0 | 0.1 | 5.3 | 2.5 | 22 | 44 | 0.4 | 30 | 303 |
| Celeriac | 88 | 42 | 1.5 | 0.3 | 9.5 | 1.8 | 43 | 115 | 0.7 | 100 | 300 |
| Celery | 92 | 14 | 0.7 | 0.2 | 3.0 | 1.6 | 40 | 24 | 0.2 | 80 | 260 |

| Chayote | 95 | 17 | 8.0 | 0.1 | 3.9 | 1.7 | 17 | 18 | 0.3 | 2 | 125 |
|---------------------|----|-----|-----|-----|------|-----|-----|-----|-----|----|-----|
| Chicory, withoof | 95 | 17 | 6.0 | 0.1 | 4.0 | 3.1 | 28 | 56 | 0.2 | 2 | 211 |
| Chinese cabbage | 95 | 13 | 1.5 | 0.2 | 2.2 | 1.0 | 105 | 37 | 8.0 | 65 | 252 |
| Collards | 91 | 30 | 2.5 | 0.4 | 5.7 | 3.6 | 145 | 10 | 0.2 | 20 | 169 |
| Cucumber | 95 | 15 | 0.7 | 0.1 | 3.6 | 0.5 | 16 | 24 | 0.3 | 2 | 147 |
| Eggplant | 95 | 24 | 1.0 | 0.2 | 5.7 | 3.4 | 6 | 25 | 0.2 | 2 | 230 |
| Endive | 94 | 17 | 1.3 | 0.2 | 3.4 | 3.1 | 52 | 28 | 8.0 | 22 | 314 |
| Garlic | 59 | 149 | 6.4 | 0.5 | 33.1 | 2.1 | 181 | 153 | 1.7 | 17 | 401 |
| Kale | 84 | 20 | 3.3 | 0.7 | 10.0 | 2.0 | 135 | 99 | 1.7 | 43 | 447 |
| Kohlrabi | 91 | 27 | 1.7 | 0.1 | 6.2 | 3.6 | 24 | 46 | 0.4 | 20 | 350 |
| Leek | 83 | 61 | 1.5 | 0.3 | 14.1 | 1.8 | 59 | 35 | 2.1 | 20 | 180 |
| Lettuce, butterhead | 96 | 13 | 1.4 | 0.2 | 2.3 | 1.1 | 35 | 33 | 1.2 | 5 | 238 |
| Lettuce, crisphead | 96 | 14 | 6.0 | 0.1 | 3.0 | 1.2 | 18 | 20 | 0.4 | 10 | 141 |
| Lettuce, green leaf | 94 | 18 | 1.3 | 0.3 | 3.5 | 0.7 | 89 | 25 | 1.4 | 6 | 264 |
| Lettuce, red leaf | 96 | 16 | 1.3 | 0.2 | 2.3 | 6.0 | 33 | 28 | 1.2 | 25 | 187 |
| Lettuce, romaine | 95 | 17 | 1.2 | 0.3 | 3.3 | 2.1 | 33 | 30 | 1.0 | œ | 247 |
| Melon, cantaloupe | 90 | 34 | 8.0 | 0.2 | 8.2 | 6.0 | 6 | 15 | 0.2 | 16 | 267 |
| Melon, casaba | 95 | 28 | 1.1 | 0.1 | 9.9 | 6.0 | 11 | 5 | 0.2 | 6 | 182 |
| Melon, honeydew | 06 | 36 | 0.5 | 0.1 | 9.1 | 8.0 | 9 | 11 | 0.2 | 18 | 228 |
| Mushroom | 95 | 22 | 3.1 | 0.3 | 3.2 | 1.2 | က | 82 | 0.5 | 4 | 314 |
| Mustard greens | 91 | 26 | 2.7 | 0.2 | 4.9 | 3.3 | 103 | 43 | 1.5 | 25 | 354 |
| Okra | 06 | 31 | 2.0 | 0.1 | 7.0 | 3.2 | 81 | 63 | 8.0 | ∞ | 303 |
| Onion, bunching | 06 | 32 | 1.8 | 0.2 | 7.3 | 5.6 | 72 | 37 | 1.5 | 16 | 276 |
| Onion, dry | 89 | 42 | 6.0 | 0.1 | 10.1 | 1.4 | 22 | 27 | 0.2 | က | 144 |
| Parsley | 88 | 36 | 3.0 | 8.0 | 6.3 | 3.3 | 138 | 58 | 6.2 | 99 | 554 |
| | | | | | | | | | | | |

TABLE 1.20. COMPOSITION OF THE EDIBLE PORTIONS OF FRESH, RAW VEGETABLES (Continued)

Amount/100 g Edible Portion

| | | | | | 0 | | <u> </u> | | | | |
|--------------------|-------|--------|---------|-----|--------------|-------|----------|------|------|------|------|
| | Water | Energy | Protein | Fat | Carbohydrate | Fiber | Ca | Ь | Fe | Na | K |
| Vegetable | (%) | (kcal) | (g) | (g) | (g) | (g) | (mg) | (mg) | (mg) | (mg) | (mg) |
| Parsnip | 80 | 75 | 1.2 | 0.3 | 18.0 | 4.9 | 36 | 71 | 9.0 | 10 | 375 |
| Pea, edible-podded | 88 | 42 | 2.8 | 0.2 | 7.6 | 2.6 | 43 | 53 | 2.1 | 4 | 200 |
| Pea, green | 42 | 81 | 5.4 | 0.4 | 14.5 | 5.1 | 25 | 108 | 1.5 | 5 | 244 |
| Pepper, hot, chile | 88 | 40 | 2.0 | 0.2 | 9.5 | 1.5 | 18 | 46 | 1.2 | 7 | 340 |
| Pepper, sweet | 94 | 20 | 6.0 | 0.2 | 4.6 | 1.7 | 10 | 20 | 0.3 | က | 175 |
| Potato | 42 | 77 | 2.0 | 0.1 | 17.5 | 2.2 | 12 | 22 | 8.0 | 9 | 421 |
| Pumpkin | 92 | 56 | 1.0 | 0.1 | 6.5 | 0.5 | 21 | 44 | 8.0 | 1 | 340 |
| Radicchio | 93 | 23 | 1.4 | 0.3 | 4.5 | 6.0 | 19 | 40 | 9.0 | 22 | 302 |
| Radish | 92 | 16 | 0.7 | 0.1 | 3.4 | 1.6 | 25 | 20 | 0.3 | 39 | 233 |
| Rhubarb | 94 | 21 | 6.0 | 0.2 | 4.5 | 1.8 | 98 | 14 | 0.2 | 4 | 288 |
| Rutabaga | 90 | 36 | 1.2 | 0.2 | 8.1 | 2.5 | 47 | 28 | 0.5 | 20 | 337 |
| Salsify | 27 | 85 | 3.3 | 0.2 | 18.6 | 3.3 | 09 | 75 | 0.7 | 20 | 380 |
| Shallot | 80 | 72 | 2.5 | 0.1 | 16.8 | I | 37 | 09 | 1.2 | 12 | 334 |
| Southern pea | 77 | 06 | 3.0 | 0.4 | 18.9 | 5.0 | 126 | 53 | 1.1 | 4 | 431 |
| Spinach | 91 | 23 | 2.9 | 0.4 | 3.6 | 2.2 | 66 | 49 | 2.7 | 79 | 558 |
| Squash, acorn | 88 | 40 | 8.0 | 0.1 | 10.4 | 1.5 | 33 | 36 | 0.7 | က | 347 |
| Squash, butternut | 98 | 45 | 1.0 | 0.1 | 11.7 | 2.0 | 48 | 33 | 0.7 | 4 | 352 |

| Squash, Hubbard | 88 | 40 | 2.0 | 0.5 | 8.7 | | 14 | 21 | 0.4 | 7 | 320 |
|------------------|----|-----|-----|-----|------|-----|-----|----|-----|-----|-----|
| Squash, scallop | 94 | 18 | 1.2 | 0.2 | 3.8 | I | 19 | 36 | 0.4 | 1 | 182 |
| Squash, summer | 92 | 16 | 1.2 | 0.2 | 3.4 | 1.1 | 15 | 38 | 0.4 | 2 | 262 |
| Squash, zucchini | 26 | 16 | 1.2 | 0.2 | 3.4 | 1.1 | 15 | 38 | 0.4 | 10 | 262 |
| Strawberry | 91 | 32 | 0.7 | 0.3 | 7.7 | 2.0 | 16 | 24 | 0.4 | 1 | 153 |
| Sweet corn | 92 | 86 | 3.2 | 1.2 | 19.0 | 2.7 | 2 | 88 | 0.5 | 15 | 270 |
| Sweet potato | 77 | 98 | 1.6 | 0.1 | 20.1 | 3.0 | 30 | 47 | 9.0 | 55 | 337 |
| Swiss chard | 93 | 19 | 1.8 | 0.2 | 3.7 | 1.6 | 51 | 46 | 1.8 | 213 | 379 |
| Taro | 71 | 112 | 1.5 | 0.2 | 26.5 | 4.1 | 43 | 84 | 9.0 | 11 | 591 |
| Tomato, green | 93 | 23 | 1.2 | 0.2 | 5.1 | 1.1 | 13 | 28 | 0.5 | 13 | 204 |
| Tomato, ripe | 92 | 18 | 6.0 | 0.2 | 3.9 | 1.2 | 10 | 24 | 0.3 | 2 | 237 |
| Turnip greens | 90 | 32 | 1.5 | 0.3 | 7.1 | 3.2 | 190 | 42 | 1.1 | 40 | 596 |
| Turnip roots | 92 | 28 | 6.0 | 0.1 | 6.4 | 1.8 | 30 | 27 | 0.3 | 29 | 191 |
| Watermelon | 92 | 30 | 9.0 | 0.2 | 7.6 | 0.4 | 7 | 10 | 0.2 | 1 | 112 |

Adapted from USDA Nutrient Database for Standard Reference, Release 17 (2005), http://www.nal.usda.gov/fnic/foodcomp/Data/SR17/reports/sr17page.htm.

9

111

19

19

2.9

3.0

0.2

0.4

13

96

Waxgourd

TABLE 1.21. VITAMIN CONTENT OF FRESH RAW, VEGETABLES

| | | | Amount/100 g Edible Portion | g Edible Porti | uo | |
|------------------|-----------|----------|-----------------------------|----------------|---------------|------------------------|
| | Vitamin A | Thiamine | Riboflavin | Niacin | Ascorbic Acid | Vitamin B _e |
| Vegetable | (IU) | (mg) | (mg) | (mg) | (mg) | (mg) |
| Artichoke | 0 | 0.07 | 0.07 | 1.05 | 11.7 | 0.12 |
| Asparagus | 756 | 0.14 | 0.14 | 96.0 | 5.6 | 0.09 |
| Bean, green | 069 | 0.08 | 0.11 | 0.75 | 16.3 | 0.07 |
| Bean, lima | 303 | 0.22 | 0.10 | 1.47 | 23.4 | 0.20 |
| Beet greens | 6,326 | 0.10 | 0.22 | 0.40 | 30.0 | 0.11 |
| Beet roots | 33 | 0.03 | 0.04 | 0.33 | 4.9 | 0.07 |
| Broccoli | 099 | 0.07 | 0.12 | 0.64 | 89.2 | 0.18 |
| Broccoli raab | 2,622 | 0.16 | 0.13 | 1.2 | 20.2 | 0.17 |
| Brussels sprouts | 754 | 0.14 | 0.09 | 0.75 | 85.0 | 0.22 |
| Cabbage, common | 171 | 0.05 | 0.04 | 0.30 | 32.2 | 0.10 |
| Cabbage, red | 1,116 | 90.0 | 0.07 | 0.42 | 57.0 | 0.21 |
| Cabbage, savoy | 1,000 | 0.07 | 0.03 | 0.30 | 31.0 | 0.19 |
| Carrot | 12,036 | 0.07 | 90.0 | 1.0 | 5.9 | 0.14 |
| Cauliflower | 13 | 90.0 | 90.0 | 0.53 | 46.4 | 0.22 |
| Celeriac | 0 | 0.05 | 90.0 | 0.70 | 8.0 | 0.17 |
| Celery | 449 | 0.02 | 90.0 | 0.32 | 3.1 | 0.07 |
| Chayote | 0 | 0.03 | 0.03 | 0.47 | 7.7 | 80.0 |
| Chicory, witloof | 53 | 9.0 | 0.03 | 0.16 | 2.8 | 0.04 |
| Chinese cabbage | 4,468 | 0.04 | 0.07 | 0.50 | 45.0 | 0.19 |

| 0.04 0.08 0.08 0.02 0.03 0.09 0.09 0.09 0.09 0.09 0.09 0.09 | 0.30 |
|--|--------|
| 35.3 2.8 2.2 6.5 31.2 12.0 62.0 12.0 3.7 3.7 24.0 36.7 24.8 24.8 24.8 60.0 60.0 40.0 242.5 | 19.7 |
| 0.74 0.10 0.65 0.40 0.70 1.00 0.40 0.40 0.32 0.32 0.33 0.33 0.23 0.60 3.85 0.80 1.00 0.08 0.08 0.08 0.08 0.08 0.08 | 1.05 |
| 0.13 0.03 0.04 0.08 0.08 0.01 0.03 0.08 0.09 0.02 0.03 0.02 0.03 0.03 0.04 0.04 0.05 0.06 0.09 0.09 0.01 0.01 0.01 0.02 0.03 0.03 0.03 0.03 0.04 0.04 0.05 0.06 0.07 0.08 0.09 0.00 | 0.03 |
| 0.05 0.03 0.04 0.08 0.09 0.00 0.00 0.00 0.00 0.00 0.00 | 0.08 |
| 6,668 105 2,167 2,167 0 15,376 3,312 502 7,405 7,405 5,807 3,382 0 0 10,500 3,75 997 8,424 640 1,087 640 1,179 3,70 | 77 |
| Collards Cucumber Eggplant Endive Garlic Kale Kohlrabi Lettuce, butterhead Lettuce, crisphead Lettuce, red leaf Lettuce, romaine Melon, cantaloupe Melon, casaba Melon, honeydew Mushroom Mushroom Mushroom Perseley Parsley | Potato |

TABLE 1.21. VITAMIN CONTENT OF FRESH RAW VEGETABLES (Continued)

| | | | Amount/100 g Edible Portion | g Edible Porti | no | |
|-------------------|-----------|----------|-----------------------------|----------------|---------------|------------------------|
| | Vitamin A | Thiamine | Riboflavin | Niacin | Ascorbic Acid | Vitamin B _e |
| Vegetable | (IU) | (mg) | (mg) | (mg) | (mg) | (mg) |
| Pumpkin | 7.384 | 0.05 | 0.11 | 09:0 | 9.0 | 0.06 |
| Radicchio | 27 | 0.03 | 0.03 | 0.26 | 8.0 | 0.06 |
| Radish | 7 | 0.01 | 0.04 | 0.25 | 14.8 | 0.07 |
| Rhubarb | 102 | 0.02 | 0.03 | 0.30 | 8.0 | 0.02 |
| Rutabaga | 2 | 0.09 | 0.04 | 0.70 | 25.0 | 0.10 |
| Salsify | 0 | 0.08 | 0.22 | 0.50 | 8.0 | 0.28 |
| Shallot | 12 | 90.0 | 0.02 | 0.2 | 8.0 | 0.35 |
| Southern pea | 0 | 0.11 | 0.15 | 1.45 | 2.5 | 0.07 |
| Spinach | 9,377 | 0.08 | 0.19 | 0.72 | 28.1 | 0.20 |
| Squash, acorn | 367 | 0.14 | 0.01 | 0.70 | 11.0 | 0.15 |
| Squash, butternut | 10,630 | 0.10 | 0.02 | 1.20 | 21.0 | 0.15 |
| Squash, Hubbard | 1,367 | 0.07 | 0.04 | 0.50 | 11.0 | 0.15 |
| Squash, scallop | 110 | 0.07 | 0.03 | 09.0 | 18.0 | 0.11 |
| Squash, summer | 200 | 0.05 | 0.14 | 0.49 | 17.0 | 0.22 |
| Squash, zucchini | 200 | 0.05 | 0.14 | 0.49 | 17.0 | 0.22 |
| Strawberry | 12 | 0.02 | 0.02 | 0.39 | 58.8 | 0.05 |
| Sweet corn | 208 | 0.20 | 90.0 | 1.70 | 6.8 | 90.0 |
| Sweet potato | 14,187 | 0.08 | 90.0 | 0.56 | 2.4 | 0.80 |
| Swiss chard | 6,116 | 0.04 | 60.0 | 0.40 | 30.0 | 0.10 |

| Taro | 92 | 0.10 | 0.03 | 09.0 | 4.5 | 0.28 |
|---------------|-----|------|------|------|------|------|
| Tomato, green | 642 | 90.0 | 0.04 | 0.50 | 23.4 | 0.08 |
| Tomato, ripe | 833 | 0.04 | 0.02 | 09.0 | 12.7 | 0.08 |
| Turnip greens | 0 | 0.07 | 0.10 | 09.0 | 0.09 | 0.26 |
| Turnip roots | 0 | 0.04 | 0.03 | 0.40 | 21.0 | 0.09 |
| Watermelon | 269 | 0.03 | 0.02 | 0.18 | 8.1 | 0.05 |
| Waxgourd | 0 | 0.04 | 0.11 | 0.40 | 13.0 | 0.04 |
| | | | | | | |

Adapted from USDA Nutrient Database for Standard Reference, Release 17 (2005), http://www.nal.usda.gov/fnic/foodcomp/Data/SR17/reports/sr17page.htm. See also http://www.5aday.com.

PART 2

PLANT GROWING AND GREENHOUSE VEGETABLE PRODUCTION

TRANSPLANT PRODUCTION

- 01 PLANT GROWING CONTAINERS
- 02 SEEDS AND SEEDING
- 03 TEMPERATURE AND TIME REQUIREMENTS
- 04 PLANT GROWING MIXES
- 05 SOIL STERILIZATION
- 06 FERTILIZING AND IRRIGATING TRANSPLANTS
- 07 PLANT GROWING PROBLEMS
- 08 CONDITIONING TRANSPLANTS
- 09 ADDITIONAL INFORMATION SOURCES ON TRANSPLANT PRODUCTION

GREENHOUSE CROP PRODUCTION

- 10 CULTURAL MANAGEMENT
- 11 CARBON DIOXIDE ENRICHMENT
- 12 SOILLESS CULTURE
- 13 NUTRIENT SOLUTIONS
- 14 TISSUE COMPOSITION
- 15 ADDITIONAL SOURCES OF INFORMATION ON GREENHOUSE VEGETABLES

TRANSPLANT PRODUCTION

Vegetable crops are established in the field by direct seeding or by use of vegetative propagules (see Part 3) or transplants. Transplants are produced in containers of various sorts in greenhouses, protected beds, and open fields. Either greenhouse-grown containerized or field-grown bare-root transplants can be used successfully. Generally, containerized transplants get off to a faster start but are more expensive. Containerized transplants, sometimes called "plug" transplants have become the norm for melons, pepper, tomato, and eggplant.

Transplant production is a specialized segment of the vegetable business that demands suitable facilities and careful attention to detail. For these reasons, many vegetable growers choose to purchase containerized or field-grown transplants from production specialists rather than grow them themselves.

TABLE 2.1. RELATIVE EASE OF TRANSPLANTING VEGETABLES (referring to bare-root transplants)¹

| Easy | Moderate | Require Special Care ² |
|--|---------------------------------------|---|
| Beet Broccoli Brussels sprouts Cabbage Cauliflower Chard Lettuce | Celery Eggplant Onion Pepper | Sweet corn Cantaloupe Cucumber Summer squash Watermelon |

 $^{^1}Although \ containerized \ transplant \ production \ is \ the \ norm \ for \ most \ vegetables, information \ on \ bare-root \ transplants \ is \ available \ at \ http://pubs.caes.uga.edu/caespubs/PDF/B1144.pdf(2003).$

² Containerized transplants are recommended.

Organic Vegetable Transplants

Organically grown vegetable transplants are not readily available from most commercial transplant producers. A good source of information on organic transplant production is at http://attra.ncat.org/attra-pub/plugs.html.

For information on organic seed production and seed handling, see J. Bonina and D. J. Cantliffe, *Seed Production and Seed Sources of Organic Vegetables* (University of Florida Cooperative Extension Service), http://edis.ifas.ufl.edu/hs227.

PLANT GROWING CONTAINERS

TABLE 2.2. ADVANTAGES AND DISADVANTAGES OF VARIOUS PLANT GROWING CONTAINERS

| Container | Advantages | Disadvantages |
|-----------------------|--|---|
| Single peat pellet | No media preparation, low storage requirement | Requires individual handling in setup, limited sizes |
| Prespaced peat pellet | No media preparation, can be handled as a unit of 50 | Limited to rather small sizes |
| Single peat pot | Good root penetration, easy to handle in field, available in large sizes | Difficult to separate, master container is required, dries out easily, may act as a wick in the field if not properly covered |
| Strip peat pots | Good root penetration, easy to handle in field, available in large sizes, saves setup and filling time | May be slow to separate in the field, dries out easily |

| Plastic flat with unit | Easily handled, reusable, good root | Requires storage during off season, may be limited in sizes |
|--|---|--|
| Plastic pack | Easily handled | Roots may grow out of container causing handling problems, limited in sizes, requires some setup labor |
| Plastic pot | Reusable, good root penetration | Requires handling as single plant |
| r ory drewname to ann mac | Easily manueu, requires less media dian similar sizes of other containers, comes in many sizes reusable | nequires regular retuinzation, plants grow slowly at first because cultural systems use low levels of nitrogen |
| Expanded polystyrene tray | Lightweight, easy to handle, various cell | Need sterilization between uses, |
| | sizes and shapes, reusable, automation | moderate investment, as trays age, |
| Injection-molded trays | Various cell sizes, reusable, long life, | Large investment, need sterilization |
| | compatible for automation | between uses |
| Vacuum-formed tray | Low capital investment | Short life span, needs sterilization |
| | | between uses, automation |
| | | incompatible due to damage to tray |
| Adapted in part from D. C. Sanders and 337, 1984). | Adapted in part from D. C. Sanders and G. R. Hughes (eds.), Production of Commercial Vegetable Transplants (North Carolina Agricultural Extension Service - 337, 1984). | msplants (North Carolina Agricultural Extension Service - |

02 SEEDS AND SEEDING

SEEDING SUGGESTIONS FOR GROWING TRANSPLANTS

 Media. Field soil alone usually is not a desirable seeding medium because it may crust or drain poorly under greenhouse conditions. Adding sand or a sand and peat mix may produce a good seeding mixture. Many growers use artificial mixes (see page 65) because of the difficulty of obtaining field soil that is free from pests and contaminating chemicals.

A desirable seeding mix provides good drainage but retains moisture well enough to prevent rapid fluctuations, has good aeration, is low in soluble salts, and is free from insects, diseases, and weed seeds.

2. Seeding. Adjust seeding rates to account for the stated germination percentages and variations in soil temperatures. Excessively thick stands result in spindly seedlings, and poor stands are wasteful of valuable bench or bed space. Seeding into containerized trays can be done mechanically using pelletized seeds. Pelletized seeds are seeds that have been coated with a clay material to facilitate planting by machine. Pelletized seeds also allow for easier singulation (one seed per cell in the tray).

Carefully control seeding depth; most seeds should be planted at 1/4 to 1/2 in. deep. Exceptions are celery, which should only be 1/8 in. deep, and the vine crops, sweet corn, and beans, which can be seeded 1 in. or deeper.

- Moisture. Maintain soil moisture in the desirable range by thorough watering after seeding and careful periodic watering as necessary. A combination of spot watering of dry areas and overall watering is usually necessary. Do not overwater.
- 4. *Temperature*. Be certain to maintain the desired temperature. Cooler than optimum temperatures may encourage disease, and warmer temperatures result in spindly seedlings. Seeded containerized trays can be placed in a germination room where temperature and humidity are controlled. Germination rate and germination uniformity are enhanced with this technique. Once germination has initiated, move the trays to the greenhouse.
- 5. Disease control. Use disease-free or treated seed to prevent early disease problems. Containers should be new or disease free. A disease-free seeding medium is essential. Maintain a strict sanitation program to prevent introduction of diseases. Carefully control

- watering and relative humidity. Use approved fungicides as drenches or sprays when necessary. Keep greenhouse environment as dry as possible with air-circulation fans and anti-condensate plastic greenhouse covers.
- 6. *Transplanting*. Start transplanting when seedlings show the first true leaves so the process can be completed before the seedlings become large and overcrowded. Seedlings in containerized trays do not require transplanting to a final transplant growing container.
- 7. Fertilization. Developing transplants need light, water, and fertilization with nitrogen, phosphorus, and potassium to develop a stocky, vigorous transplant, ready for the field. Excessive fertilization, especially with nitrogen, leads to spindly, weak transplants that are difficult to establish in the field. Excessive fertilization of tomato transplants with nitrogen can lead to reduced fruit yield in the field. Only 40–60 ppm nitrogen is needed in the irrigation solution for tomato. Many commercial soilless transplant mixes have a starter nutrient charge, but this charge must be supplemented with a nutrient solution after seedlings emerge.

TABLE 2.3. APPROXIMATE SEED REQUIREMENTS FOR PLANT GROWING

| Vegetable | Plants/oz Seed | Seed Required to Produce 10,000 Transplants |
|------------------|-------------------|---|
| Asparagus | 550 | 11⁄4 lb |
| Broccoli | 5,000 | 2 oz |
| Brussels sprouts | 5,000 | 2 oz |
| Cabbage | 5,000 | 2 oz |
| Cantaloupe | 500 | 11/4 lb |
| Cauliflower | 5,000 | 2 oz |
| Celery | 15,000 | 1 oz |
| Sweet corn | 100 | 6½ lb |
| Cucumber | 500 | 11/4 lb |
| Eggplant | 2,500 | 4 oz |
| Lettuce | 10,000 | 1 oz |
| Onion | 4,000 | 3 oz |
| Pepper | 1,500 | 7 oz |
| Summer squash | 200 | 31/4 lb |
| Tomato | 4,000 | 3 oz |
| Watermelon | 200 | 31⁄4 lb |

To determine seed requirements per acre:

$$\frac{Desired\ plant\ population}{10,000} \times seed\ required\ for\ 10,000\ plants$$

Example 1: To grow enough broccoli for a population of 20,000 plants/acre:

$$\frac{20,000}{10,000} \times 2 = 4 \text{ oz seed}$$

 $\it Example~2:$ To grow enough summer squash for a population of 3600 plants/acre:

$$\frac{3600}{10,000} \times 3^{1/4} = 1^{1/4}$$
 lb approximately

TABLE 2.4. RECOMMENDATIONS FOR TRANSPLANT PRODUCTION USING CONTAINERIZED TRAYS

| 2 oz | |
|---|---|
| $1\frac{1}{4}$ lb 2 oz 1 oz 1 oz 2 oz 1 oz 2 oz 2 oz 1 $\frac{1}{4}$ lb 4 oz 4 oz | $\begin{array}{ccccc} 1.0 & 1.4 & \text{lb} \\ 0.8-1.0 & 2 & \text{oz} \\ 0.5-0.8 & 1 & \text{oz} \\ 0.8-1.0 & 2 & \text{oz} \\ 1.0 & 1.4 & \text{lb} \\ 1.0 & 4 & \text{oz} \end{array}$ |

RECOMMENDATIONS FOR TRANSPLANT PRODUCTION USING CONTAINERIZED TRAYS (Continued) TABLE 2.4.

| Time Required (weeks) | 4 | 10 - 12 | 2-2 | 3-4 | 2-2 | 3-4 |
|---|---------|-----------|-----------|--------------|-----------|--------------|
| $^{\rm pH}_{\rm Tolerance^3}$ | 6.0–6.8 | 8.9 - 0.9 | 5.5 - 6.8 | 5.5 - 6.8 | 5.5 - 6.8 | 5.0 - 6.8 |
| Germination (days) ² | 23 | 4 | ∞ | က | 5 | က |
| Optimum Germination Temperature (°F) | 75 | 75 | 85 | 06 | 85 | 06 |
| Seeding Depth (in.) | 1/8 | 1/4 | 1/4 | 1/2 | 1/4 | 1/2 |
| Seed Required for 10,000 Transplants | 1 oz | 3 oz | 7 oz | $3^{1/4}$ lb | 3 oz | $3^{1/4}$ lb |
| Cell Size (in.) | 0.5-0.8 | 0.5 - 0.8 | 0.5 - 0.8 | 0.5 - 0.8 | 1.0 | 1.0 |
| Crop^1 | Lettuce | Onion | Pepper | Squash | Tomato | Watermelon |

Adapted from C. S. Vavrina, An Introduction to the Production of Containerized Transplants, Florida Cooperative Extension Service Fact Sheet HS 849 (2002),

Other crops can be grown as transplants by matching seed types and growing according to the above specifications (example: endive = lettuce). Sweet corn can be transplanted, but tap root is susceptible to breakage. http://edis.ifas.ufl.edu/HS126.

³ Plug pH will increase over time with alkaline irrigation water. ²Under optimum germination temperatures.

04 PLANT GROWING MIXES

SOILLESS MIXES FOR TRANSPLANT PRODUCTION

Most commercial transplant producers use some type of soilless media for growing vegetable transplants. Most such media employ various mixtures of sphagnum peat and vermiculite or perlite, and growers may incorporate some fertilizer materials as the final media are blended. For small growers or on-farm use, similar types of media can be purchased premixed and bagged. Most of the currently used media mixes are based on variations of the Cornell mix recipe below:

TABLE 2.5. CORNELL PEAT-LITE MIXES

| Component | Ar | nount (cu y | rd) |
|-----------------------------------|-------------------------------|----------------|----------------------|
| Spagnum peat | | 0.5 | |
| Horticultural vermicul | ite | 0.5 | |
| Additions for Spec | cific Uses (amoun | t/cu yd) | |
| | | Greenh | ouse Tomatoes |
| ${f Addition}$ | Seedling or Bedding Plants | Liquid Feed | Slow-release Feed |
| Ground limestone (lb) | 5 | 10 | 10 |
| 20% superphosphate (lb) | 1–2 | 2.5 | 2.5 |
| Calcium or potassium nitrate (lb) | 1 | 1.5 | 1.5 |
| Trace element mix (oz) | 2 | 2 | 2 |
| Osmocote (lb) | 0 | 0 | 10 |
| Mag Amp (lb) | 0 | 0 | 5 |
| Wetting agent (oz) | 3 | 3 | 3 |
| | | | |

Adapted from J. W. Boodley and R. Sheldrake Jr., Cornell Peat-lite Mixes for Commercial Plant Growing, New York State Agricultural Experiment Station, Station Agriculture Information Bulletin 43 (1982).

05 SOIL STERILIZATION

TABLE 2.6. STERILIZATION OF PLANT GROWING SOILS

| Agent | Method | Recommendation |
|----------|-------------------------|---|
| Heat | Steam Aerated steam | 30 min at 180°F 30 min at 160°F |
| | Electric | 30 min at 180°F |
| Chemical | Chloropicrin | 3–5 cc/cu ft of soil. Cover for 1–3 days. Aerate for 14 days or until no odor is detected before using. |
| | Vapam Methyl bromide | 1 qt/100 sq ft. Allow 7–14 days before use. The phase-out of methyl bromide: http://www.epa.gov/spdpublc/mbr/ |

 ${\it Caution:} \ {\it Chemical funigants are highly toxic.} \ {\it Follow manufacturer's recommendations on the label.}$

Soluble salts, manganese, and ammonium usually increase after heat sterilization. Delay using heat-sterilized soil for at least 2 weeks to avoid problems with these toxic materials.

Adapted from K. F. Baker (ed.), The UC System for Producing Healthy Container-grown Plants, California Agricultural Experiment Station Manual 23 (1972).

TABLE 2.7. TEMPERATURES REQUIRED TO DESTROY PESTS IN COMPOSTS AND SOIL

| Pests | 30-min Temperature (°F) |
|---------------------------------------|-------------------------|
| Nematodes | 120 |
| Damping-off organisms | 130 |
| Most pathogenic bacteria and fungi | 150 |
| Soil insects and most viruses | 160 |
| Most weed seeds | 175 |
| Resistant weeds and resistant viruses | 212 |

Adapted from K. F. Baker (ed.), The UC System for Producing Healthy Container-grown Plants, California Agricultural Experiment Station Manual 23 (1972).

06 FERTILIZING AND IRRIGATING TRANSPLANTS

TABLE 2.8. FERTILIZER FORMULATIONS FOR TRANSPLANT FERTILIZATION BASED ON NITROGEN AND POTASSIUM CONCENTRATIONS

| | N an | nd K ₂ O Con | centrations | (ppm) |
|--------------------------|------|-------------------------|-------------|-------|
| Fertilizer | 50 | 100 | 200 | 400 |
| | | oz/1 | 00 gal¹ | |
| 20-20-20 | 3.3 | 6.7 | 13.3 | 26.7 |
| 15-0-15 | 4.5 | 8.9 | 17.8 | 35.6 |
| 20-10-20 | 3.3 | 6.7 | 13.3 | 26.7 |
| Ammonium nitrate | 1.4 | 2.9 | 5.7 | 11.4 |
| + potassium nitrate | 1.5 | 3.0 | 6.1 | 12.1 |
| Calcium nitrate | 3.0 | 6.0 | 12.0 | 24.0 |
| + potassium nitrate | 1.5 | 3.0 | 6.0 | 12.0 |
| Ammonium nitrate | 1.2 | 2.5 | 4.9 | 9.9 |
| + potassium nitrate | 1.5 | 3.0 | 6.0 | 12.0 |
| + monoammonium phosphate | 0.5 | 1.1 | 2.2 | 4.3 |

Adapted from P. V. Nelson, "Fertilization," in E. J. Holcomb (ed.). Bedding Plants IV: A Manual on the Culture of Bedding Plants as a Greenhouse Crop (Batavia, Ill.: Ball, 1994), 151–176. Used with permission.

 $^{^{1}}$ 1.0 oz in 100 gal is equal to 7.5 g in 100 L.

TABLE 2.9. ELECTRICAL CONDUCTIVITY (EC) IN SOIL AND PEAT-LITE MIXES

| Mineral Soils (mS) ¹ | Peat-lite Mixes (mS) ¹ | | Interpretations |
|---------------------------------|---|-----------|--|
| 2.0+ | 3.5+ | Excessive | Plants may be severely injured. |
| 1.76-2.0 | 2.25-3.5 | Very high | Plants may grow adequately, but range is near danger zone, especially if soil dries. |
| 1.26–1.75 | 1.76–2.25 | High | Satisfactory for established plants. May be too high for seedlings and cuttings. |
| 0.51-1.25 | 1.0-1.76 | Medium | Satisfactory for general plant growth. Excellent range for constant fertilization program. |
| 0.0-0.50 | 0.0-1.0 | Low | Low EC does no harm but may indicate low nutrient concentration. |

Adapted from R. W. Langhans and E. T. Paparozzi, "Irrigation" in E. J. Holcomb (ed.), $Bedding\ Plant\ IV:A\ Manual\ on\ the\ Culture\ of\ Bedding\ Plants\ as\ a\ Greenhouse\ Crop\ (Batavia,\ Ill.:\ Ball,\ 1994),\ 139-150.$ Used with permission.

 $^{^1\}mathrm{EC}$ of soil determined from 1 part dry soil to 2 parts water. EC of mix determined from level tsp dry mix to 40 mL water.

TABLE 2.10. MAXIMUM ACCEPTABLE WATER QUALITY INDICES FOR BEDDING PLANTS

| Variable | Plug Production | Finish Flats and Pots |
|--|---|--|
| pH ¹ (acceptable range) Alkalinity ² Hardness ³ EC Ammonium-N Boron | 5.5-7.5 1.5 me/L (75 ppm) 3.0 me/L (150 ppm) 1.0 mS 20 ppm 0.5 ppm | 5.5–7.5 2.0 me/L (100 ppm) 3.0 me/L (150 ppm) 1.2 mS 40 ppm 0.5 ppm |

Adapted from P. V. Nelson, "Fertilization," in E. J. Holcomb (ed.), Bedding Plants IV: A Manual on the Culture of Bedding Plants as a Greenhouse Crop (Batavia, Ill.: Ball, 1994), 151–176. Used with permission.

IRRIGATION OF TRANSPLANTS

There are two systems for application of water (and fertilizer solutions) to transplants produced in commercial operations: overhead sprinklers and subirrigation. Sprinkler systems apply water or nutrient solution by overhead water sprays from various types of sprinkler or emitter applicators. Advantages of sprinklers include the ability to apply chemicals to foliage and the ability to leach excessive salts from media. Disadvantages include high investment cost and maintenance requirements. Chemical and water application can be variable in poorly maintained systems, and nutrients can be leached if excess amounts of water are applied. One type of subirrigation uses a trough of nutrient solution in which the transplant trays are periodically floated, sometimes called ebb and flow or the float system. Water and soluble nutrients are absorbed by the media and move upward into the media. Advantages of this system include uniform application of water and nutrient solution to all flats in a trough or basin. Subirrigation with recirculation of the nutrient solution minimizes the potential for pollution because all nutrients are kept in an enclosed system.

¹pH not very important alone; alkalinity level more important.

 $^{^2}$ Moderately higher alkalinity levels are acceptable when lower amounts of limestone are incorporated into the substrate during its formulation. Very high alkalinity levels require acid injection into water source.

³ High hardness values are not a problem if calcium and magnesium concentrations are adequate and soluble salt level is tolerable.

Challenges with subirrigation include the need for care to avoid contamination of the entire trough with a disease organism. In addition, subirrigation systems restrict the potential to vary nutrient needs of different crops or developmental stages of transplants within a specific subirrigation trough.

With either production system, transplant growers must exercise care in application of water and nutrients to the crop. Excessive irrigation can leach nutrients. Irrigation and fertilization programs are linked. Changes in one program can affect the efficiency of the other program. Excessive fertilization can lead to soluble salt injury, and excessive nitrogen application can lead to overly vegetative transplants. More information on transplant irrigation and the float system is available from:

http://pubs.caes.uga.edu/caespubs/pubs/PDF/B1144.pdf (2003) http://www.utextension.utk.edu/publications/pbfiles/PB819.pdf (1999)

07 PLANT GROWING PROBLEMS

TABLE 2.11. DIAGNOSIS AND CORRECTION OF TRANSPLANT DISORDERS

| | Symptoms | Possible Causes ¹ | Corrective Measures |
|----|---------------------|---|--|
| 1. | Spindly growth | Shade, cloudy weather, excessive watering, excessive temperature | Provide full sun, reduce temperature, restrict watering, ventilate or reduce night temperature, fertilize less frequently, provide adequate space. |
| 2. | Budless plants | Many possible causes; no conclusive cause | Maintain optimum temperature and fertilization programs. |
| 3. | Stunted plants | Low fertility | Apply fertilizer frequently in low concentration. |
| | A. Purple leaves | Phosphorus deficiency | Apply a soluble, phosphorus-rich fertilizer at 50 ppm P every irrigation for up to 1 week. |
| | B. Yellow leaves | Nitrogen deficiency | Apply N fertilizer solution at 50–75 ppm each irrigation for 1 week. Wash the foliage with water after application. |
| | C. Wilted shoots | Pythium root rot, flooding damage, soluble salt damage to roots | Check for <i>Pythium</i> or other disease organism. Reduce irrigation amounts and reduce fertilization. |
| | D. Discolored roots | High soluble salts from overfertilization; high soluble salts from poor soil sterilization | Leach the soil by excess watering. Do not sterilize at temperatures above 160°F. Leach soils before planting when soil tests indicate high amounts of soluble salts. |
| | E. Normal roots | Low temperature | Maintain suitable day and night temperatures. |

TABLE 2.11. DIAGNOSIS AND CORRECTION OF TRANSPLANT DISORDERS (Continued)

| | Symptoms | Possible Causes ¹ | Corrective Measures |
|----|---|--|--|
| 4. | Tough, woody plants | Overhardening | Apply starter solution (10-55-10 or 15-30-15 at 1 oz/gal to each 6-12 sq ft bench area) 3-4 days before transplanting. |
| 5. | Water-soaked and decayed stems near the soil surface | Damping off | Use a sterile, well-drained medium. Adjust watering and ventilation practices to provide a less moist environment. Use approved fungicidal drenches. |
| 6. | Poor root growth | Poor soil aeration; poor soil drainage; low soil fertility; excess soluble salts; low temperature; residue from chemical sterilization; herbicide residue | Determine the cause and take corrective measures. |
| 7. | Green algae or mosses growing on soil surface | High soil moisture, especially in shade or during cloudy periods | Adjust watering and ventilation practices to provide a less moist environment. Use a better-drained medium. |

¹Possible causes are listed here; however, more than one factor may lead to the same symptom. Therefore, plant producers should thoroughly evaluate all possible causes of a specific disorder.

SUGGESTIONS FOR MINIMIZING DISEASES IN VEGETABLE TRANSPLANTS

Successful vegetable transplant production depends on attention to disease control. With the lack of labeled chemical pesticides, growers must focus on cultural and greenhouse management strategies to minimize opportunities for disease organisms to attack the transplant crop.

Greenhouse environment: Transplant production houses should be located at least several miles from any vegetable production field to avoid the entry of disease-causing agents in the house. Weeds around the greenhouse should be removed and the area outside the greenhouse maintained free of weeds, volunteer vegetable plants, and discarded transplants.

Media and water: All media and irrigation water should be pathogen free. If media are to be blended on site, all mixing equipment and surfaces must be routinely sanitized. Irrigation water should be drawn from pathogen-free sources. Water from ponds or recycling reservoirs should be avoided.

Planting material: Only pathogen-free seed or plant plugs should be brought into the greenhouse to initiate new transplant crops. Transplant producers should not accept seeds of unknown quality for use in transplant production. This can be a problem, especially when producing small batches of transplants from small packages of seed, e.g., for a variety trial.

Cultural practices: Attention must be given to transplant production practices such as fertilization, irrigation, and temperature so that plant vigor is optimum. Free moisture, from sprinkler irrigation or condensation, on plants should be avoided. Ventilation of houses by exhaust fans and horizontal airflow fans helps reduce free moisture on plants. Growers should follow a strict sanitation program to prevent introduction of disease organisms into the house. Weeds under benches must be removed. Outside visitors to the greenhouse should be strictly minimized, and all visitors and workers should walk through a disinfecting foot bath. All plant material and soil mix remaining between transplant crops should be removed from the house.

CONTROLLING TRANSPLANT HEIGHT

One aspect of transplant quality involves transplants of size and height that are optimum for efficient handling in the field during transplantation and for rapid establishment. Traditional means for controlling plant height included withholding water and nutrients and/or application of growth regulator chemicals. Today, growth regulator chemicals are not labeled for vegetable transplant production. Plant height control research focuses on nutrient management, temperature manipulation, light quality, and mechanical conditioning of plants.

Nutrient management: Nitrogen applied in excess often causes transplants to grow tall rapidly. Using low-N solutions with 30–50 parts per million (ppm) nitrogen helps control plant height when frequent (daily)

- irrigations are needed. Higher concentrations of N may be needed when irrigations are infrequent (every 3 to 4 days). Often, an intermediate N concentration (e.g., 80 ppm) is chosen for the entire transplant life cycle, and an excessive growth rate often results. Irrigation frequency should guide the N concentration. Research has shown that excessive N applied to the transplant can lead to reduced fruit yield in the field.
- Moisture management: Withholding water is a time-tested method of reducing plant height, but transplants can be damaged by drought. Sometimes transplants growing in Styrofoam trays along the edge of a greenhouse walkway dry out faster than the rest of the transplants in the greenhouse. These dry plants are always shorter compared to the other transplants. Overwatering transplants should therefore be avoided, and careful attention should be given to irrigation timing.
- Light intensity: Transplants grown under reduced light intensity stretch; therefore, growers must give attention to maximizing light intensity in the greenhouse. Aged polyethylene greenhouse covers should be replaced and greenhouse roofs and sides should be cleaned periodically, especially in winter. Supplementing light intensity for some transplant crops with lights may be justified.
- Temperature management: Transplants grown under cooler temperatures (e.g., 50°F) are shorter than plants grown under warmer temperatures. Where possible, greenhouse temperatures can be reduced or plants moved outdoors. Under cool temperatures, the transplant production cycle is longer by several days and increased crop turnaround time may be unacceptable. For some crops, such as tomato, growing transplants under cool temperatures may lead to fruit quality problems, e.g., catfacing of fruits.
- Mechanical conditioning: Shaking or brushing transplants frequently results in shorter transplants. Transplants can be brushed by several physical methods—for example, by brushing a plastic rod over the tops of the plants. This technique obviously should be practiced on dry plants only to avoid spreading disease organisms.
- Day/night temperature management: The difference between the day and night temperatures (DIF) can be employed to help control plant height. With a negative DIF, day temperature is cooler than night temperature. Plants grown with a positive DIF are taller than plants grown with a zero or negative DIF. This system is not used during germination but rather is initiated when the first true leaves appear. The DIF system requires the capability to control the greenhouse temperature and is most applicable to temperate regions in winter and spring, when day temperatures are cool and greenhouses can be heated.

TABLE 2.12. VEGETABLE TRANSPLANT RESPONSE TO THE DIFFERENCE IN DAY AND NIGHT TEMPERATURE (DIF)

| Common Name | Response to DIF |
|------------------|-----------------|
| Broccoli | 3 |
| Brussels sprouts | 3 |
| Cabbage | 3 |
| Cantaloupe | 3 |
| Cucumber | 1–2 |
| Eggplant | 3 |
| Pepper | 0-1 |
| Squash | 2 |
| Tomato | 2 |
| Watermelon | 3 |

From E. J. Holcomb (ed.), Bedding Plants IV (Batavia, Ill.: Ball, 1994). Original source: J. E. Erwin and R. D. Heins, "Temperature Effects on Bedding Plant Growth," Bulletin 42:1–18, Minnesota Commercial Flower Growers Association (1993). Used with permission.

¹0 = no response; 3 = strong response

08 CONDITIONING TRANSPLANTS

Objective: To prepare plants to withstand stress conditions in the field.

These may be low temperatures, high temperatures, drying winds, low soil moisture, or injury to the roots in transplanting. Growth rates decrease during conditioning, and the energy otherwise used in growth is stored in the plant to aid in resumption of growth after transplanting. Conditioning is used as an alternative to the older term, hardening.

Methods: Any treatment that restricts growth increases hardiness. Coolseason crops generally develop hardiness in proportion to the severity of the treatment and length of exposure and when well-conditioned withstand subfreezing temperatures. Warm-season crops, even when highly conditioned, do not withstand temperatures much below freezing.

- Water supply. Gradually reduce water by watering lightly at less frequent intervals. Do not allow the plants to dry out suddenly, with severe wilting.
- Temperature. Expose plants to lower temperatures (5–10°F) than
 those used for optimum growth. High day temperatures may reverse
 the effects of cool nights, making temperature management difficult.
 Do not expose biennials to prolonged cool temperatures, which induces
 bolting.
- 3. Fertility. Do not fertilize, particularly with nitrogen, immediately before or during the initial stages of conditioning. Apply a starter solution or liquid fertilizer 1 or 2 days before field setting and/or with the transplanting water (see page 78).
- 4. *Combinations*. Restricting water and lowering temperatures and fertility, used in combination, are perhaps more effective than any single approach.

Duration: Seven to ten days are usually sufficient to complete the conditioning process. Do not impose conditions so severe that plants are overconditioned in case of delayed planting because of poor weather. Overconditioned plants require too much time to resume growth, and early yields may be lower.

PRETRANSPLANT HANDLING OF CONTAINERIZED TRANSPLANTS

Field performance of transplants is related not only to production techniques in the greenhouse but also to handling techniques before field planting. In the containerized tray production system, plants can be delivered to the field in the trays if the transplant house is near the production fields. For long-distance transport, the plants are usually pulled from the trays and packed in boxes. Tomato plants left in trays until field planting tend to have more rapid growth rates and larger fruit yields than when transplants were pulled from the trays and packed in boxes. Storage of pulled and packed tomato plants also reduces yields of large fruits compared to plants kept in the trays. If pulled plants must be stored prior to planting, storage temperatures should be selected to avoid chilling or overheating the transplants. Transplants that must be stored for short periods can be kept successfully at 50-55°F.

TABLE 2.13. STARTER SOLUTIONS FOR FIELD TRANSPLANTING¹

| Materials | Quantity to Use in Transplanter Tank | | | | | |
|--|---|--|--|--|--|--|
| Readily Soluble Commercial Mixtures | | | | | | |
| 8-24-8, 11-48-0 | (Follow manufacturer's directions.) | | | | | |
| 23-21-17, 13-26-13 | Usually 3 lb/50 gal water | | | | | |
| 6-25-15, 10-52-17 | | | | | | |
| Straight Nitrogen Chemicals | | | | | | |
| Ammonium sulfate, calcium nitrate, or sodium nitrate | $2\frac{1}{2}$ lb/50 gal water | | | | | |
| Ammonium nitrate | $1\frac{1}{2}$ lb/50 gal water | | | | | |
| Commercial Solutions | | | | | | |
| 30% nitrogen solution | $1\frac{1}{2}$ pt/50 gal water | | | | | |
| 8-24-0 solution (N and P_2O_5) | 2 qt/50 gal water | | | | | |
| Regular Commercial Fertilizer Grades | | | | | | |
| 4-8-12, 5-10-5, 5-10-10, etc. | | | | | | |
| 1 lb/gal for stock solution; stir well and let settle | 5 gal stock solution with 45 gal water | | | | | |

ADDITIONAL INFORMATION SOURCES ON TRANSPLANT PRODUCTION

- Charles W. Marr, Vegetable Transplants (Kansas State University, 1994), http://www.oznet.ksu.edu/library/hort2/MF1103.pdf.
- W. Kelley et al., Commercial Production of Vegetable Transplants (University of Georgia, 2003), http://pubs.caes.uga.edu/caespubs/pubcd/b1144.htm.
- J. Bodnar and R. Garton, *Growing Vegetable Transplants in Plug Trays* (Ontario Ministry of Agriculture, Food, and Rural Affairs, 1996), http://www.omafra.gov.on.ca/english/crops/facts/96-023.htm.
- L. Greer and K. Adam, Organic Plug and Transplant Production (2002), http://attra.ncat.org/attra-pub/plugs.html.
- D. Krauskopf, Vegetable Transplant Production Tips (Michigan State University), http://www.horticulture.wisc.edu/freshveg/Publications/ WFFVGC%202005/Vegetable%20Transplant%20Production%20Tips.doc.
- R. Styer and D. Koranski, *Plug and Transplant Production: A Grower's Guide* (Batavia, Ill.: Ball).

GREENHOUSE CROP PRODUCTION

10 CULTURAL MANAGEMENT

CULTURAL MANAGEMENT OF GREENHOUSE VEGETABLES

Although most vegetables can be grown successfully in greenhouses, only a few are grown there commercially. Tomato, cucumber, and lettuce are the three most commonly grown vegetables in commercial greenhouses. Some general cultural management principles are discussed here.

Greenhouse Design

Successful greenhouse vegetable production depends on careful greenhouse design and construction. Consideration must be provided for environmental controls, durability of components, and ease of operations, among other factors. The publications listed at the end of this chapter offer helpful advice for construction.

Sanitation

There is no substitute for good sanitation for preventing insect and disease outbreaks in greenhouse crops.

To keep greenhouses clean, remove and destroy all dead plants, unnecessary mulch material, flats, weeds, etc. Burn or bury all plant refuse. Do not contaminate streams or water supplies with plant refuse. Weeds growing in and near the greenhouse after the cropping period should be destroyed. Do not attempt to overwinter garden or house plants in the greenhouses. Pests can also be maintained and ready for an early invasion of vegetable crops. To prevent disease organisms from carrying over on the structure of the greenhouse and on the heating pipes and walks, spray with formaldehyde (3 gal 37% formalin in 100 gal water). Immediately after spraying, close the greenhouse for 4–5 days, then ventilate. *Caution:* Wear a respirator when spraying with formaldehyde.

A 15–20-ft strip of carefully maintained lawn or bare ground around the greenhouse helps decrease trouble from two-spotted mites and other pests. To reduce entry of whiteflies, leafhoppers, and aphids from weeds and other plants near the greenhouses, spray the area growth occasionally with a labeled insecticide and control weeds around the greenhouse. Some pests can be excluded with properly designed screens.

Monitoring Pests

Insects such as greenhouse and silverleaf whiteflies, thrips, and leaf miners are attracted to shades of yellow and fly toward that color. Thus, insect traps can be made by painting pieces of board with the correct shade of yellow pigment and then covering the paint with a sticky substance. Similar traps are available commercially from several greenhouse supply sources. By placing a number of traps within the greenhouse range, it is possible to check infestations daily and be aware of early infestations. Control programs can then be commenced while populations are low.

Two-spotted mites cannot be trapped in this way, but infestations usually begin in localized areas. Check leaves daily and begin control measures as soon as the first infested areas are noted.

Spacing

Good-quality container-grown transplants should be set in arrangements to allow about 4 sq ft/plant for tomato, 5 sq ft/plant for American-type cucumber, and 7–9 sq ft/plant for European-type cucumber. Lettuce requires 36–81 sq in./plant.

Temperature

Greenhouse to mato varieties may vary in their temperature requirements, but most varieties per form well at a day minimum temperature of $70-75^{\circ}\mathrm{F}$ and a night minimum temperature of $62-64^{\circ}\mathrm{F}$. Temperatures for cucumber seedlings should be $72-76^{\circ}\mathrm{F}$ day and $68^{\circ}\mathrm{F}$ night. In a few weeks, night temperature can be gradually lowered to $62-64^{\circ}\mathrm{F}$. Night temperatures for lettuce can be somewhat lower than for to mato and cucumber.

In northern areas, provisions should be made to heat water to be used in greenhouses to about 70° F.

Pruning and Tying

Greenhouse tomatoes and cucumbers are usually pruned to a single stem by frequent removal of axillary shoots or suckers. Other pruning systems are possible and sometimes used. Various tying methods are used; one common method is to train the pruned plant around a string suspended from an overhead wire.

Pollination

Greenhouse tomatoes must be pollinated by hand or with bumblebees to assure a good set of fruit. This involves tapping or vibrating each flower cluster to transfer the pollen grains from the anther to the stigma. This should be done daily as long as there are open blossoms on the flower cluster. The pollen is transferred most readily during sunny periods and with the most difficulty on dark, cloudy days. The electric or battery-operated hand vibrator is the most widely accepted tool for vibrating tomato flower clusters. Most red-fruited varieties pollinate more easily than pink-fruited varieties and can often be pollinated satisfactorily by tapping the overhead support wires or by shaking flowers in the airstream of a motor-driven backpack air-blower. Modern growers now use bumblebees for pollinating tomato. Specially reared hives of bumblebees are purchased by the grower for this purpose.

Pollination of European seedless cucumbers causes off-shape fruit, so bees must be excluded from the greenhouse. To help overcome this, gynoecious cultivars have been developed that bear almost 100% female flowers. Only completely gynoecious and parthenocarpic (set fruits without pollination) cultivars are now recommended for commercial production.

American-type cucumbers require bees for pollination. One colony of honeybees per house should be provided. It is advisable to shade colonies from the afternoon sun and to avoid excessively high temperatures and humidities. Honeybees fly well in glass and polyethylene plastic houses but fail to work under certain other types of plastic. Under these conditions, crop failures may occur through lack of pollination.

Adapted from Ontario Ministry of Agriculture Publication 356 (1985–1986) and from G. Hochmuth, "Production of Greenhouse Tomatoes," Florida Greenhouse Vegetable Production Handbook, vol. 3, (2001), http://edis.ifas.ufl.edu/CV266, and from G. Hochmuth and R. Hochmuth, Keys to Successful Tomato and Cucumber Production in Perlite Media (2003), http://edis.ifas.ufl.edu/HS169. See also:

- G. Hochmuth and R. Hochmuth, Design Suggestions and Greenhouse Management for Vegetable Production in Perlite and Rockwool Media in Florida (2004), http://edis.ifas.ufl.edu/CV195.
- Ray Bucklin, "Physical Greenhouse Design Considerations," Florida Greenhouse Vegetable Production Handbook, vol. 2 (2001), http://edis.ifas.ufl.edu/CV254.

11 CARBON DIOXIDE ENRICHMENT

CARBON DIOXIDE ENRICHMENT OF GREENHOUSE ATMOSPHERES

The beneficial effects of adding carbon dioxide $(\mathrm{CO_2})$ to the northern greenhouse environment are well established. The crops that respond most consistently to supplemental $\mathrm{CO_2}$ are cucumber, lettuce, and tomato, although almost all other greenhouse crops also benefit. $\mathrm{CO_2}$ enrichment of southern greenhouses probably has little benefit due to frequent ventilation requirements under the warm temperatures.

Outside air contains about 340 parts per million (ppm) CO_2 by volume. Most plants grow well at this level, but if levels are higher, the plants respond by producing more sugars. During the day, in a closed greenhouse, the plants use the CO_2 in the air and reduce the level below the normal 340 ppm. This is the point at which CO_2 addition is most important. Most crops respond to CO_2 additions up to about 1300 ppm. Somewhat lower concentrations are adequate for seedlings or when growing conditions are less than ideal.

Carbon dioxide can be obtained by burning natural gas, propane, or kerosene and directly from containers of pure CO_2 . Each source has potential advantages and disadvantages. When natural gas, propane, or kerosene is burned, not only is CO_2 produced but also heat, which can supplement the normal heating system. Incomplete combustion or contaminated fuels may cause plant damage. Most sources of natural gas and propane have sufficiently low levels of impurities, but you should notify your supplier of your intention to use the fuel for CO_2 addition. Sulfur levels in the fuel should not exceed 0.02% by weight.

A number of commercial companies have burners available for natural gas, propane, and liquid fuels. The most important feature of a burner is that it burns the fuel completely.

Because photosynthesis occurs only during daylight hours, CO_2 addition is not required at night, but supplementation is recommended on dull days. Supplementation should start approximately 1 hour before sunrise, and the system should be shut off 1 hour before sunset. If supplemental lighting is used at night, intermittent addition of CO_2 or the use of a CO_2 controller may be helpful.

When ventilators are opened, it is not possible to maintain high CO₂ levels. However, it is often during these hours (high light intensity and

temperature) that CO_2 supplementation is beneficial. Because maintaining optimal levels is impossible, maintaining at least ambient levels is suggested. A CO_2 controller, whereby the CO_2 concentration can be maintained at any level above ambient, is therefore useful.

One important factor is an adequate distribution system. The distribution of CO_2 mainly depends on the air movement in the greenhouse(s), for CO_2 does not travel far by diffusion. This means that if a single source of CO_2 is used for a large surface area or several connecting greenhouses, a distribution system must be installed. Air circulation (horizontal fans or a fanjet system) that moves a large volume of air provides uniform distribution within the greenhouse.

Adapted from Ontario Ministry of Agriculture and Food AGDEX 290/27 (1984) and from G. Hochmuth and R. Hochmuth (eds.), Florida Greenhouse Vegetable Production Handbook, vol. 3, "Greenhouse Vegetable Crop Production Guide," Florida Cooperative Extension Fact Sheet HS784 (2001), http://edis.ifas.ufl.edu/pdffiles/CV/CV26200.pdf.

12 SOILLESS CULTURE

SOILLESS CULTURE OF GREENHOUSE VEGETABLES

Well-managed field soils supply crops with sufficient water and appropriate concentrations of the 13 essential inorganic elements. A combination of desirable soil chemical, physical, and biotic characteristics provides conditions for extensive rooting, which results in anchorage, the third general quality provided to crops by soil.

When field soils are used in the greenhouse for repeated intensive crop culture, desirable soil characteristics deteriorate rapidly. Diminishing concentrations of essential elements and impaired physical properties are restored as in the field by applications of lime, fertilizer, and organic matter. Deterioration of the biotic quality of the soil by increased pathogenic microorganism and nematode populations is restricted mostly by steam sterilization.

Even with the best management, soils may deteriorate in quality over time. In addition, the costs—particularly of steam sterilization—of maintaining greenhouse soils in good condition have escalated so that soilless culture methods are competitive with or perhaps more economically favorable than soil culture. Accordingly, recent years have seen a considerable shift from soil culture to soilless culture in greenhouses. Liquid and solid media systems are used.

Liquid Soilless Culture

The nutrient film technique (NFT) is the most commonly used liquid system.

NFT growing systems consist of a series of narrow channels through which nutrient solution is recirculated from a supply tank. A plumbing system of plastic tubing and a submersible pump in the tank are the basic components. The channels are generally constructed of opaque plastic film or plastic pipe; asphalt-coated wood and fiberglass are also used. The basic characteristic of all NFT systems is the shallow depth of solution maintained in the channels. Flow is usually continuous, but sometimes systems are operated intermittently by supplying solution a few minutes every hour. The purpose of intermittent flow is to assure adequate aeration of the root systems. This also reduces the energy required, but under rapid growth conditions, plants may experience water stress if the flow period is

too short or infrequent. Therefore, intermittent flow management seems better adapted to mild temperature periods or to plantings during the early stages of development. Capillary matting is sometimes used in the bottom of NFT channels, principally to avoid the side-to-side meandering of the solution stream around young root systems; it also acts as a reservoir by retaining nutrients and water during periods when flow ceases.

NFT channels are frequently designed for a single row of plants with a channel width of 6--8 inches. Wider channels of 12--15 in. are used to accommodate two rows of plants, but meandering of the shallow solution stream becomes a greater problem with greater width. To minimize this problem, small dams can be created at intervals down the channel by placing thin wooden sticks across the stream, or the channel may be lined with capillary matting. The channels should be sloped 4--6 in. per 100 ft to maintain gravity flow of the solution. Flow rate into the channels should be in the range of 1--2 qt/min.

Channel length should be limited to a maximum of 100 feet in order to minimize increased solution temperature on bright days. The ideal solution temperature for tomato is 68–77°F. Temperatures below 59° or above 86°F decrease plant growth and tomato yield. Channels of black plastic film increase solution temperature on sunny days. During cloudy weather, it may be necessary to heat the solution to the recommended temperature. Solution temperatures in black plastic channels can be decreased by shading or painting the surfaces white or silver. As an alternative to channels lined with black polyethylene, 4–6-in. PVC pipe may be used. Plant holes are spaced appropriately along the pipe. The PVC system is permanent once it is constructed; polyethylene-lined channels must be replaced for each crop. Initial costs are higher for the PVC, and sanitation between crops may be more difficult. In addition, PVC pipe systems are subject to root flooding if root masses clog pipes.

Solid Soilless Culture

Lightweight media in containers or bags and rockwool mats are the most commonly used media culture systems.

Media Culture

Soilless culture in bags, pots, or troughs with a lightweight medium is the simplest, most economical, and easiest to manage of all soilless systems. The most common media used in containerized systems of soilless culture are perlite, peat-lite, or a mixture of bark and wood chips. Container types range from long wooden troughs in which one or two rows of plants are

grown to polyethylene bags or rigid plastic pots containing one to three plants. Bag or pot systems using bark chips or peat-lite are in common use throughout the United States and offer major advantages over other types of soilless culture:

- 1. These materials have excellent retention qualities for nutrients and water
- 2. Containers of medium are readily moved in or out of the greenhouse whenever necessary or desirable.
- 3. They are lightweight and easily handled.
- The medium is useful for several successive crops.
- 5. The containers are significantly less expensive and less time-consuming to install.
- In comparison with recirculated hydroponic systems, the nutrientsolution system is less complicated and less expensive to manage.

From a plant nutrition standpoint, the latter advantage is of significant importance. In a recirculated system, the solution is continuously changing in its nutrient concentration because of differential plant uptake. In the bag or pot system, the solution is not recirculated. Nutrient solution is supplied from a fertilizer proportioner or large supply tank to the surface of the medium in a sufficient quantity to wet the medium. Any excess is drained away from the system through drain holes in the base of the containers. Thus, the concentration of nutrients in solution supplied to the plants is the same at each application. This eliminates the need to sample and analyze the solution periodically to determine necessary adjustments and avoids the possibility of solution excess or deficiencies.

In the bag or pot system, the volume of medium per container varies from about 1/2 cu ft in vertical polyethylene bags or pots to 2 cu ft in lay-flat bags. In the vertical bag system, 4-mil black polyethylene bags with prepunched drain holes at the bottom are common. One, but sometimes two, tomato or cucumber plants are grown in each bag. Lay-flat bags accommodate two or three plants. In either case, the bags are aligned in rows with spacing appropriate to the type of crop. It is good practice to place vertical bags or pots on a narrow sheet of plastic film to prevent root contact or penetration into the underlying soil. Plants in lay-flat bags, which have drainage slits (or overflow ports) cut along the sides an inch or so above the base, also benefit from a protective plastic sheet beneath them.

Nutrient solution is delivered to the containers by supply lines of black polyethylene tubing, spaghetti tubing, spray sticks, or ring drippers in the containers. The choice of application system is important in order to provide proper wetting of the medium at each irrigation. Texture and porosity of the growing medium and the surface area to be wetted are important considerations in making the choice. Spaghetti tubing provides a point-source wetting pattern, which might be appropriate for fine-textured media that allow water to be conducted laterally with ease. In lay-flat bags, single spaghetti tubes at individual plant holes provide good wetting of peat-lite. In a vertical bag containing a porous medium, a spray stick with a 90-degree spray pattern does a good job of irrigation if it is located to wet the majority of the surface. Ring drippers are also a good choice for vertical bags, although somewhat more expensive. When choosing an application system for bag or container culture, remember that the objective of irrigation is to distribute nutrient solution uniformly so that all of the medium is wet.

Rockwool and Perlite Culture

Rockwool is made by melting various types of rocks at very high temperatures. The resulting fibrous particles are formed into growing blocks or mats that are sterile and free of organic matter. The growing mats have a high water-holding capacity, no buffering capacity, and an initial pH of 7–8.5, which is lowered quickly with application of slightly acidic nutrient solutions. Uncovered mats, which are covered with polyethylene during setup, or polyethylene enclosed mats can be purchased. The mats are 8–12 in. wide, 36 in. long, and 3 in. thick. Perlite, a volcanic mineral, is heated and expanded into small, granular particles. Perlite has a high water-holding capacity but provides good aeration.

The greenhouse floor should be carefully leveled and covered with 3-mil black/white polyethylene, which restricts weed growth and acts as a light reflector with the white side up. The mats are placed end to end to form a row; single or double rows are spaced for the crop and greenhouse configuration.

A complete nutrient solution made with good-quality water is used for initial soaking of the mats. Large volumes are necessary because of the high water-holding capacity of the mats. Drip irrigation tubing or spaghetti tubing arranged along the plant row are used for initial soaking and, later, for fertigation. After soaking, uncovered mats are covered with polyethylene and drainage holes made in the bagged mats.

Cross-slits, corresponding in size to the propagating blocks, are made in the polyethylene mat cover at desired in-row plant spacings; usually two plants are grown in each 30-in.-long mat. The propagating blocks containing the transplant are placed on the mat, and the excess polyethylene from the cross-slit is arranged around the block. Frequent irrigation is required until

plant roots are established in the mat; thereafter, fertigation is applied 4–10 times a day depending on the growing conditions and stage of crop growth. The mats are leached with good-quality water when samples taken from the mats with a syringe have increased conductivity readings.

Adapted in part from H. Johnson Jr., G. J. Hochmuth, and D. N. Maynard, "Soilless Culture of Greenhouse Vegetables," Florida Cooperative Extension Bulletin 218 (1985), and from M. Sweat and G. Hochmuth, "Production Systems," Florida Greenhouse Vegetable Production Handbook, vol. 3, Fact Sheet HS785, http://edis.ifas.ufl.edu/pdffiles/CV/CV26300.pdf.

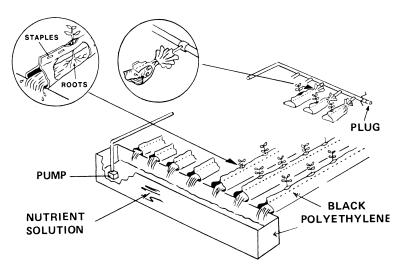


Figure 2.1. NFT culture system using polyethylene film to hold plants and supply nutrient solution through a recirculation system (From Florida Cooperative Extension Bulletin 218).

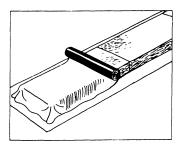


Figure 2.2. Arranged mats are covered with white/black polyethylene.

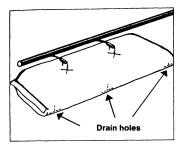


Figure 2.3. Irrigation system and drainage holes for rockwool mats enclosed in a polyethylene bag.

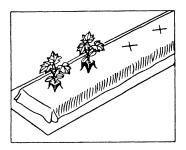


Figure 2.4. Cross-slits are made to accommodate transplants in propagation blocks.

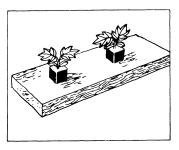


Figure 2.5. Ordinarily, two plants are placed in each 30-in.-long mat.

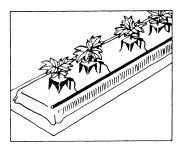


Figure 2.6. Fertigation supplied by spaghetti tubing to each plant.

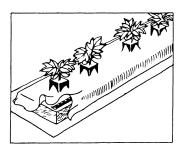


Figure 2.7. Fertigation supplied by drip irrigation tubing.

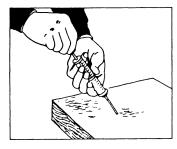


Figure 2.8. Removal of sample from rockwool mat with a syringe for conductivity determination.

Figures 2.2. through 2.8. Adapted from GRODAN® Instructions for cultivation—cucumbers, Grodania A/S, Denmark and used with permission.

13 NUTRIENT SOLUTIONS

NUTRIENT SOLUTIONS FOR SOILLESS CULTURE

Because the water and/or media used for soilless culture of greenhouse vegetables is devoid of essential elements, these must be supplied in a nutrient solution.

Commercially available fertilizer mixtures may be used, or nutrient solutions can be prepared from individual chemical salts. The most widely used and generally successful nutrient solution is one developed by D. R. Hoagland and D. I. Arnon at the University of California. Many commercial mixtures are based on their formula.

Detailed directions for preparation of Hoagland's nutrient solutions, which are suitable for experimental or commercial use, and the formulas for several nutrient solutions suitable for commercial use follow.

TABLE 2.14. HOAGLAND'S NUTRIENT SOLUTIONS

| Salt | Stock Solution (g to make 1 L) | Final Solution (ml to make 1 L) | | | |
|---|-----------------------------------|---------------------------------|--|--|--|
| | Solution 1 | | | | |
| $Ca(NO_3)_2 \cdot 4H_2O$ | 236.2 | 5 | | | |
| KNO_3 | 9.2 2 | | | | |
| KH_2PO_4 | 136.1 | 1 | | | |
| $MgSO_4 \cdot 7H_2O$ | 246.5 | 2 | | | |
| | Solution 2 | | | | |
| Ca(NO ₃) ₂ · 4H ₂ O | 236.2 | 4 | | | |
| KNO ₃ | 101.1 | 6 | | | |
| $NH_4H_2PO_4$ | 115.0 | 1 | | | |
| $MgSO_4 \cdot 7H_2O$ | 246.5 | 2 | | | |

Micronutrient Solution

| Compound | Amount (g) Dissolved in 1 L Water |
|---|--------------------------------------|
| ${ m H_{3}BO_{3}} \\ { m MnCl_{2} \cdot 4H_{2}O} \\ { m ZnSO_{4} \cdot 7H_{2}O} \\ { m CuSO_{4} \cdot 5H_{2}O} \\ { m H_{2}MoO_{4} \cdot H_{2}O}$ | 2.86 1.81 0.22 0.08 0.02 |

Iron Solution

Iron chelate, such as Sequestrene 330, made to stock solution containing 1 g actual iron/L. Sequestrene 330 is 10% iron; thus, 10 g/L are required. The amounts of other chelates must be adjusted on the basis of their iron content.

Procedure: To make 1 L of Solution 1, add 5 ml $Ca(NO_3)_2 \cdot 4H_2O$ stock solution, 5 ml KNO_3 , 1 ml KH_2PO_4 , 2ml $MgSO_4 \cdot 7H_2O$, 1 ml micronutrient solution, and 1 ml iron solution to 800 ml distilled water. Make up to 1 L. Some plants grow better on Solution 2, which is prepared in the same way.

Adapted from D. R. Hoagland and D. I. Arnon, "The Water-culture Method for Growing Plants Without Soil," California Agricultural Experiment Station Circular 347 (1950).

SOME NUTRIENT SOLUTIONS FOR COMMERCIAL GREENHOUSE VEGETABLE PRODUCTION

These solutions are designed to be supplied directly to greenhouse vegetable crops.

TABLE 2.15. JOHNSON'S SOLUTION

| Compound | | | | | | | | | Amount (g/100 gal water) | | | |
|-------------------------|--------------------------|----------|--------------------------|----|----|--------------------------|-----------|--------------------------|--------------------------|------------------------------------|-----------|---------------------------|
| Potassium nitrate | | | | | | | | | 95 | | | |
| Monopotassium phosphate | | | | | | | 54 | | | | | |
| Magnesium sulfate | | | | | | | 95 | | | | | |
| Calcium nitrate | | | | | | | | 173 | | | | |
| Chelated iron (FeDTPA) | | | | | | | | 9 | | | | |
| Boric acid | | | | | | | | 0.5 | | | | |
| Manganese sulfate | | | | | | | | 0.3 | | | | |
| Zinc sulfate | | | | | | | | 0.04 | | | | |
| Copper sulfate | | | | | | | | 0.01 | | | | |
| Molybdic acid | | | | | | | | | 0.0 | 05 | | |
| nioij said deid | | | | | | | | | 00 | | | |
| | $\underline{\mathbf{N}}$ | <u>P</u> | $\underline{\mathbf{K}}$ | Ca | Mg | $\underline{\mathbf{s}}$ | <u>Fe</u> | $\underline{\mathbf{B}}$ | Mn | $\underline{\mathbf{Z}\mathbf{n}}$ | <u>Cu</u> | $\underline{\mathbf{Mo}}$ |
| ppm | 105 | 33 | 138 | 85 | 25 | 33 | 2.3 | 0.23 | 0.26 | 0.024 | 0.01 | 0.007 |

TABLE 2.16. JENSEN'S SOLUTION

| | Con | npour | nd | | | | | | | | Amoun 00 gal v | - |
|---------------------------------------|----------|----------|----------|-----------|------|----------|-----------|--------------------------|------|------|-------------------|------|
| Magn | esium | sulfa | ate | | | | | | | | 187 | |
| Mono | potass | ium j | phospl | nate | | | | | | | 103 | |
| Potas | sium r | nitrat | e | | | | | | | | 77 | |
| Calcium nitrate | | | | | | | 189 | | | | | |
| Chelated iron (FeDTPA) | | | | | | 9.6 | | | | | | |
| Boric acid | | | | | | 1.0 | | | | | | |
| Manganese chloride | | | | | 0.9 | | | | | | | |
| e e e e e e e e e e e e e e e e e e e | | | | | 0.05 | i | | | | | | |
| • | | | | | 0.02 | 2 | | | | | | |
| Zinc sulfate | | | | | | | 0.15 | i | | | | |
| | <u>N</u> | <u>P</u> | <u>K</u> | <u>Ca</u> | Mg | <u>s</u> | <u>Fe</u> | $\underline{\mathbf{B}}$ | Mn | Zn | Cu | Mo |
| ppm | 106 | 62 | 156 | 93 | 48 | 64 | 3.8 | 0.46 | 0.81 | 0.09 | 0.05 | 0.03 |

Adapted from H. Johnson, Jr., G. J. Hochmuth, and D. N. Maynard, "Soilless Culture of Greenhouse Vegetables," Florida Cooperative Extension Service Bulletin 218 (1985).

TABLE 2.17. NUTRIENT SOLUTION FORMULATION FOR TOMATO GROWN IN PERLITE OR ROCKWOOL IN FLORIDA

| | | | Stage of Growth | | |
|---------|--|---|--|--|---|
| | 1 Transplant to First Cluster | 2 First Cluster to Second | 3 Second Cluster to Third | 4 Third Cluster to Fifth | 5 Fifth Cluster to Termination |
| Stock A | 3.3 pt Phosphorus ¹ 6 lb KCl 10 lb MgSO ₄ 10 g CuSO ₄ 35 g MnSO ₄ 10 g ZnSO ₄ 40 g Solubor 3 ml Molybdenum ² | 3.3 pt Phosphorus 6 lb KCl 10 lb MgSO ₄ 10 g CuSO ₄ 35 g MnSO ₄ 10 g ZnSO ₄ 37 m Molybdenum 3 ml Molybdenum | 3.3 pt Phosphorus 6 lb KCl 10 lb MgSO ₄ 2 lb KNO ₃ 10 g CuSO ₄ 35 g MnSO ₄ 10 g ZnSO ₄ 36 g Solubor 3 ml Molybdenum | 3.3 pt Phosphorus 6 lb KCl 12 lb MgSO ₄ 2 lb KNO ₃ 10 g CuSO ₄ 35 g MnSO ₄ 10 g ZnSO ₄ 40 g Solubor 3 ml Molybdenum | 3.3 pt Phosphorus 6 lb KCl 12 lb MgSO ₄ 6 lb KNO ₃ 1 lb NH ₄ NO ₃ 1 lb S CuSO ₄ 35 g MnSO ₄ 10 g ZnSO ₄ 40 g Solubor 3 ml Molybdenum |

TABLE 2.17. NUTRIENT SOLUTION FORMULATION FOR TOMATO GROWN IN PERLITE OR ROCKWOOL IN FLORIDA (Continued)

Stage of Growth

| | 1 | 2 | 3 | 4 | 5 |
|---------|--|--|--|--|--|
| | Transplant to | First Cluster | Second Cluster | Third Cluster | Fifth Cluster |
| | First Cluster | to Second | to Third | to Fifth | to Termination |
| Stock B | 2.1 gal $Ca(NO_3)_2^3$ or 11.5 lb dry $Ca(NO_3)_2$ 0.7 lb Fe 330^4 | 2.4 gal $Ca(NO_3)_2$ or 13.1 lb dry $Ca(NO_3)_2$ 0.7 lb Fe 330 | 2.7 gal $Ca(NO_3)_2$ or 14.8 lb dry $Ca(NO_3)_2$ 0.7 lb Fe 330 | 3.3 gal Ca(NO ₃) ₂ or 18.0 lb dry Ca(NO ₃) ₂ 0.7 lb Fe 330 | 3.3 gal Ca(NO ₃₎₂ or 18.0 lb dry Ca(NO ₃₎₂ 0.7 lb Fe 330 |

Adapted from G. Hochmuth (ed.), Florida Greenhouse Vegetable Production Handbook, vol. 3, Florida Cooperative Extension Service SP-48 (1991).

¹Phosphorus from phosphoric acid (13 lb/gal specific wt., 23% P)

 $^{^2}$ Molybdenum from liquid sodium molybdate (11.4 lb/gal specific wt., 17% Mo) 3 Liquid Ca(NO₂); from a 7-0-11 (N-P₂O₂-K₂O-Ca) solution

⁴ Iron as Sequestrene 330 (10% Fe)

TABLE 2.18. RECOMMENDED NUTRIENT SOLUTION CONCENTRATIONS FOR TOMATO GROWN IN ROCKWOOL OR PERLITE IN FLORIDA

| | | | Stage of Growth | | |
|---------------|--------------------------------|----------------------------|---|---------------------------|---------------------------------|
| | | 67 5 | | 4 2 | |
| Nutrient | Transplant to First Cluster | First Cluster to Second | Second Cluster to Third | Third Cluster to Fifth | Fifth Cluster to Termination |
| | | i | | | |
| | | Final delivere | Final delivered nutrient solution concentration (ppm) | entration (ppm) | |
| ; | Š | ć | 9 | 9 | 1 |
| Z | 70 | 80 | 100 | 120 | 150 |
| Ь | 20 | 20 | 50 | 20 | 20 |
| K | 120 | 120 | 150 | 150 | 200 |
| Ca | 150 | 150 | 150 | 150 | 150 |
| $_{ m Mg}$ | 40 | 40 | 40 | 20 | 20 |
| ∞ | 20 | 20 | 20 | 09 | 09 |
| Fe | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| Cu | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Mn | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| m Zn | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| В | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Mo | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| | | | | | |

Cooperative Extension Service Fact Sheet HS787, http://edis.ifas.ufl.edu/pdffiles/CV/CV26500.pdf and G. Hochmuth and R. Hochmuth, Nutrient Solution Adapted from G. Hochmuth, "Fertilization Management for Greenhouse Vegetables," Florida Greenhouse Vegetable Production Handbook, vol. 3, Florida Formulation for Hydroponic (Perlite, Rockwool, NFT) Tomatoes in Florida (2001), http://edis.ifas.ufl.edu/CV216.

14 TISSUE COMPOSITION

TABLE 2.19. APPROXIMATE NORMAL TISSUE COMPOSITION OF HYDROPONICALLY GROWN GREENHOUSE VEGETABLES¹

| Element | Tomato | Cucumber |
|--------------------|-------------------|-------------------|
| K | 5–8% | 8–15% |
| Ca | 2–3% | 1-3% |
| Mg | 0.4 - 1.0% | 0.3-0.7% |
| NO ₃ -N | 14,000–20,000 ppm | 10,000-20,000 ppm |
| PO_4 -P | 6,000-8,000 ppm | 8,000–10,000 ppm |
| Fe | 40–100 ppm | 90–120 ppm |
| Zn | 15–25 ppm | 40–50 ppm |
| Cu | 4–6 ppm | 5–10 ppm |
| Mn | 25-50 ppm | 50–150 ppm |
| Mo | 1–3 ppm | 1–3 ppm |
| В | 20-60 ppm | 40–60 ppm |

Adapted from H. Johnson, *Hydroponics: A Guide to Soilless Culture Systems*, University of California Division of Agricultural Science Leaflet 2947 (1977).

¹ Values are for recently expanded leaves, 5th or 6th from the growing tip, petiole analysis for macronutrients, leaf blade analysis for micronutrients. Expressed on a dry weight basis.

TABLE 2.20. SUFFICIENCY NUTRIENT RANGES FOR SELECTED GREENHOUSE VEGETABLE CROPS USING DRIED MOST RECENTLY MATURED WHOLE LEAVES

| | _ | g of Harvest eason | Just Before Harvest | | |
|---------------------------------|--|---|--|--|--|
| Element | Tomato | Cucumber | Lettuce | | |
| | | percent | | | |
| N P K | 3.5-4.0 0.4-0.6 2.8-4.0 | 2.5–5.0 0.5–1.0 3.0–6.0 | 2.1–5.6 0.5–0.9 4.0–8.0 | | |
| Ca Mg S | $0.5-2.0 \\ 0.4-1.0 \\ 0.4-0.8$ | 0.8–6.0 0.4–0.8 0.4–0.8 | 0.9-2.0 0.4-0.8 0.2-0.5 | | |
| | | parts per mi | llion | | |
| B Cu Fe Mn Mo Zn | 35-60 $8-20$ $50-200$ $50-125$ $1-5$ $25-60$ | $40-100 \\ 4-10 \\ 90-150 \\ 50-300 \\ 1-3 \\ 50-150$ | 25-65 5-18 50-200 25-200 0.5-3.0 30-200 | | |

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ADDITIONAL SOURCES OF INFORMATION ON GREENHOUSE VEGETABLES

University of Georgia, http://pubs.caes.uga.edu/caespubs/pubcd/B1182.htm.

Organic herbs, http://attra.ncat.org/attra-pub/gh-herbhold.html.

Mississippi State University, http://msucares.com/crops/comhort/index.html.

Mississippi State University, http://msucares.com/pubs/publications/p1828.htm.

North Carolina State University, http://www.ces.ncsu.edu/depts/hort/greenhouse_veg/.

University of Arizona, http://ag.arizona.edu/hydroponictomatoes/.

University of Florida, http://smallfarms.ifas.ufl.edu/greenhouse/.

List of greenhouse manufacturers/suppliers, http://nfrec-sv.ifas.ufl.edu/gh_suppliers.htm.

PART 3

- 01 TEMPERATURES FOR VEGETABLES
- 02 SCHEDULING SUCCESSIVE PLANTINGS
- 03 TIME REQUIRED FOR SEEDLING EMERGENCE
- 04 SEED REQUIRMENTS
- 05 PLANTING RATES FOR LARGE SEEDS
- 06 SPACING OF VEGETABLES
- 07 PRECISION SEEDING
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01 TEMPERATURES FOR VEGETABLES

COOL-SEASON AND WARM-SEASON VEGETABLES

Vegetables generally can be divided into two broad groups. *Cool-season vegetables* develop edible vegetative parts, such as roots, stems, leaves, and buds or immature flower parts. Sweet potato and other tropical root crops (root used) and New Zealand spinach (leaf and stem used) are exceptions to this rule. *Warm-season vegetables* develop edible immature and mature fruits. Pea and broad bean are exceptions, being cool-season crops.

Cool-season crops generally differ from warm-season crops in the following respects:

- 1. They are hardy or frost tolerant.
- 2. Seeds germinate at cooler soil temperatures.
- 3. Root systems are shallower.
- 4. Plant size is smaller.
- Some, the biennials, are susceptible to premature seed stalk development from exposure to prolonged cool weather.
- 6. They are stored near 32°F, except for the white potato. Sweet corn is the only warm-season crop held at 32°F after harvest.
- 7. The harvested product is not subject to chilling injury at temperatures between 32° and 50°F, as is the case with some of the warm-season vegetables.

TABLE 3.1. CLASSIFICATION OF VEGETABLE CROPS ACCORDING TO THEIR ADAPTATION TO FIELD TEMPERATURES

| | Cool-season Crop | 98 |
|---|--|--|
| Hardy ¹ | | Half-hardy ¹ |
| Asparagus Broad bean Broccoli Brussels sprouts Cabbage Chive Collards Garlic Horseradish Kale | Kohlrabi Leek Mustard Onion Parsley Pea Radish Rhubarb Spinach Turnip | Beet Carrot Cauliflower Celery Chard Chicory Chinese cabbage Globe artichoke Endive Lettuce Parsnip Potato Salsify |
| | Warm-season Cro | ps |
| Ten | $ m der^1$ | Very Tender ¹ |
| Cowpea New Zeala Snap bean Soybean Sweet corn Tomato | | Cantaloupe Cucumber Eggplant Lima bean Okra Pepper, hot Pepper, sweet Pumpkin Squash Sweet potato Watermelon |

Adapted from A. A. Kader, J. M. Lyons, and L. L. Morris, "Postharvest Responses of Vegetables to Preharvest Field Temperatures," *HortScience* 9:523–529 (1974).

¹Relative resistance to frost and light freezes.

TABLE 3.2. GROWING DEGREE DAY BASE TEMPERATURES

| Crop | Base Temperature (°F) ¹ | |
|--------------|------------------------------------|--|
| Asparagus | 40 | |
| Bean, snap | 50 | |
| Beet | 40 | |
| Broccoli | 40 | |
| Cantaloupe | 50 | |
| Carrot | 38 | |
| Collards | 40 | |
| Cucumber | 55 | |
| Eggplant | 60 | |
| Lettuce | 40 | |
| Onion | 35 | |
| Okra | 60 | |
| Pea | 40 | |
| Pepper | 50 | |
| Potato | 40 | |
| Squash | 45 | |
| Strawberry | 39 | |
| Sweet corn | 48 | |
| Sweet potato | 60 | |
| Tomato | 51 | |
| Watermelon | 55 | |

Adapted from D. C. Sanders, H. J. Kirk, and C. Van Den Brink, "Growing Degree Days in North Carolina," North Carolina Agricultural Extension Service AG-236 (1980).

 $^{^{\}rm 1}{\rm Temperature}$ below which growth is negligible.

TABLE 3.3. APPROXIMATE MONTHLY TEMPERATURES FOR BEST GROWTH AND QUALITY OF VEGETABLE CROPS

Some crops can be planted as temperatures approach the proper range. Cool-season crops grown in the spring must have time to mature before warm weather. Fall crops can be started in hot weather to ensure a sufficient period of cool temperature to reach maturity. Within a crop, varieties may differ in temperature requirements; hence this listing provides general rather than specific guidelines.

| Temperatures | (°F) |
|--------------|------|
| | |

| Optimum | Minimum | Maximum | Vegetable |
|---------|---------|---------|---|
| 55–75 | 45 | 85 | Chicory, chive, garlic, leek, onion, salsify, scolymus, scorzonera, shallot |
| 60–65 | 40 | 75 | Beet, broad bean, broccoli, Brussels sprouts, cabbage, chard, collards, horseradish, kale, kohlrabi, parsnip, radish, rutabaga, sorrel, spinach, turnip |
| 60–65 | 45 | 75 | Artichoke, cardoon, carrot, cauliflower, celeriac, celery, Chinese cabbage, endive, Florence fennel, lettuce, mustard, parsley, pea, potato |
| 60-70 | 50 | 80 | Lima bean, snap bean |
| 60-75 | 50 | 95 | Sweet corn, southern pea, New Zealand spinach |
| 65 - 75 | 50 | 90 | Chayote, pumpkin, squash |
| 65 - 75 | 60 | 90 | Cucumber, cantaloupe |
| 70-75 | 65 | 80 | Sweet pepper, tomato |
| 70–85 | 65 | 95 | Eggplant, hot pepper, martynia, okra, roselle, sweet potato, watermelon |

TABLE 3.4. SOIL TEMPERATURE CONDITIONS FOR VEGETABLE SEED GERMINATION¹

| Vegetable | Minimum (°F) | $\begin{array}{c} \text{Optimum Range} \\ \text{(°F)} \end{array}$ | $ \begin{array}{c} Optimum \\ (^{\circ}F) \end{array} $ | Maximum (°F) |
|--------------|-----------------|--|---|-----------------|
| A | 50 | CO 05 | 7.5 | 0.5 |
| Asparagus | 50 | 60–85 | 75 | 95 |
| Bean | 60 | 60–85 | 80 | 95 |
| Bean, lima | 60 | 65–85 | 85 | 85 |
| Beet | 40 | 50-85 | 85 | 95 |
| Cabbage | 40 | 45–95 | 85 | 100 |
| Cantaloupe | 60 | 75–95 | 90 | 100 |
| Carrot | 40 | 45–85 | 80 | 95 |
| Cauliflower | 40 | 45–85 | 80 | 100 |
| Celery | 40 | 60–70 | 70^{2} | 85^{2} |
| Chard, Swiss | 40 | 50-85 | 85 | 95 |
| Corn | 50 | 60 - 95 | 95 | 105 |
| Cucumber | 60 | 60–95 | 95 | 105 |
| Eggplant | 60 | 75–90 | 85 | 95 |
| Lettuce | 35 | 40-80 | 75 | 85 |
| Okra | 60 | 70-95 | 95 | 105 |
| Onion | 35 | 50-95 | 75 | 95 |
| Parsley | 40 | 50-85 | 75 | 90 |
| Parsnip | 35 | 50-70 | 65 | 85 |
| Pea | 40 | 40 - 75 | 75 | 85 |
| Pepper | 60 | 65-95 | 85 | 95 |
| Pumpkin | 60 | 70-90 | 90 | 100 |
| Radish | 40 | 45-90 | 85 | 95 |
| Spinach | 35 | 45-75 | 70 | 85 |
| Squash | 60 | 70-95 | 95 | 100 |
| Tomato | 50 | 60-85 | 85 | 95 |
| Turnip | 40 | 60-105 | 85 | 105 |
| Watermelon | 60 | 70-95 | 95 | 105 |

 $^{^{1}}$ Compiled by J. F. Harrington, Department of Vegetable Crops, University of California, Davis.

² Daily fluctuation to 60°F or lower at night is essential.

02 SCHEDULING SUCCESSIVE PLANTINGS

Successive plantings are necessary to ensure a continuous supply of produce. This seemingly easy goal is in fact extremely difficult to achieve because of interrupted planting schedules, poor stands, and variable weather conditions.

Maturity can be predicted in part by use of days to harvest or heat units. Additional flexibility is provided by using varieties that differ in time and heat units to reach maturity. Production for fresh market entails the use of days to harvest, while some processing crops may be scheduled using the heat unit concept.

Fresh Market Crops

Sweet corn is used as an example because it is an important fresh-market crop in many parts of the country and requires several plantings to obtain a season-long supply.

- 1. Select varieties suitable for your area that mature over time. We illustrate with five fictitious varieties maturing in 68–84 days from planting, with 4-day intervals between varieties.
- 2. Make the first planting as early as possible in your area.
- 3. Construct a table like the one following and calculate the time of the next planting, so that the earliest variety used matures 4 days after "Late" in the first planting. We chose to use "Mainseason" as the earliest variety in the second planting; thus, 88 days 80 days = 8 days elapsed time before the second and subsequent plantings.
- 4. As sometimes happens, the third planting was delayed 4 days by rain. To compensate for this delay, "Midseason" is selected as the earliest variety in the third planting to provide corn 96 days after the first planting.

TABLE 3.5. EXAMPLES OF SWEET CORN PLANTINGS

| | | | Time (days) | |
|----------|--------------|----------------|------------------------|---------------------|
| Planting | Variety | To Maturity | From First Planting | To Next Planting |
| First | Early | 68 | 68 | |
| 11150 | Second Early | 72 | 72 | |
| | Midseason | 76 | 76 | |
| | Mainseason | 80 | 80 | |
| | Late | 84 | 84 | |
| | | | | 8 |
| Second | Mainseason | 80 | 88 | |
| | Late | 84 | 92 | |
| | | | | 12 |
| Third | Midseason | 76 | 96 | |
| | Mainseason | 80 | 100 | |
| | Late | 84 | 104 | |

Adapted from H. Tiessen, "Scheduled Planting of Vegetable Crops," Ontario Ministry of Agriculture and Food AGDEX 250/22 (1980).

Processing Crops

The heat unit system is used to schedule plantings and harvests for some processing crops, most notably pea and sweet corn. The use of this system implies that accumulated temperatures over a selected base temperature are a more accurate means of measuring growth than a time unit such as days.

In simplest form, heat units are calculated as follows:

$$\frac{\text{Maximum} + \text{minimum daily temperature}}{2} - \text{base temperature}$$

The base temperature is $40^{\circ}F$ for pea and $50^{\circ}F$ for sweet corn. A number of variations to this basic formula are proposed to further extend its usefulness.

Heat unit requirements to reach maturity are determined for most processing pea and sweet corn varieties and many snap bean varieties. Processors using the heat unit system assist growers in scheduling plantings to coincide with processing plant operating capacity.

03 TIME REQUIRED FOR SEEDLING EMERGENCE

DAYS REQUIRED FOR SEEDLING EMERGENCE AT VARIOUS SOIL TEMPERATURES FROM SEED PLANTED 1/2 IN. DEEP TABLE 3.6.

The days from planting to emergence constitute the time interval when a preemergence weed control treatment can be used safely and effectively. More days are required with deeper seeding because of cooler temperatures and the greater distance of growth.

| | 104 | 28 | I | NG | I | I | I | NG | I | I | NG | I | I |
|-----------------------|-----------|-----------|------------|------------|------|---------|------------|--------|-------------|--------|-------------|----------|----------|
| | 95 | 20 | NG | 9 | 5 | I | I | 6 | | NG | က | က | I |
| | 98 | 12 | 7 | 9 | 5 | 4 | က | 9 | 5 | NG | 4 | က | 5 |
| e (°F) | 77 | 10 | 7 | œ | 5 | 5 | 4 | 9 | 5 | NG | 4 | 4 | œ |
| Soil Temperature (°F) | 89 | 15 | 18 | 11 | 9 | 9 | œ | 7 | 9 | 7 | 7 | 9 | 13 |
| Soil 1 | 59 | 24 | 31 | 16 | 10 | 6 | | 10 | 10 | 12 | 12 | 13 | 1 |
| | 50 | 53 | NG | NG | 17 | 15 | 1 | 17 | 20 | 16 | 22 | NG | 1 |
| | 41 | NG | I | NG | 42 | I | 1 | 51 | I | 41 | NG | NG | I |
| | 32 | NG | 1 | NG | 1 | 1 | 1 | ŊĊ | I | NG | ŊĊ | ŊĊ | 1 |
| | Vegetable | Asparagus | Bean, lima | Bean, snap | Beet | Cabbage | Cantaloupe | Carrot | Cauliflower | Celery | Corn, sweet | Cucumber | Eggplant |

| TABLE 3.6. DAYS REQUIRED FOR SEEDLING EMERGENCE AT VARIOUS SOIL TEMPERATURES FROM | SEED PLANTED ½ IN. DEEP (Continued) |
|---|-------------------------------------|
| TABLE 3.6. | |

| | | | | Soil | Soil Temperature (*f.) | re (*F) | | | |
|------------|-----|----|----|------|------------------------|---------|----|----|-----|
| Vegetable | 32 | 41 | 50 | 59 | 89 | 77 | 86 | 95 | 104 |
| Lettuce | 49 | 15 | 7 | 4 | က | 23 | က | ŊĠ | NG |
| Okra | NG | NG | NG | 27 | 17 | 13 | 7 | 9 | 7 |
| Onion | 136 | 31 | 13 | 7 | 5 | 4 | 4 | 13 | NG |
| Parsley | I | I | 29 | 17 | 14 | 13 | 12 | 1 | I |
| Parsnip | 172 | 57 | 27 | 19 | 14 | 15 | 32 | NG | NG |
| Pea | I | 36 | 14 | 6 | 8 | 9 | 9 | 1 | I |
| Pepper | NG | NG | NG | 25 | 13 | 8 | 8 | 6 | NG |
| Radish | NG | 29 | 11 | 9 | 4 | 4 | က | I | |
| Spinach | 63 | 23 | 12 | 7 | 9 | ō | 9 | NG | NG |
| Tomato | NG | NG | 43 | 14 | 8 | 9 | 9 | 6 | NG |
| Turnip | NG | NG | 5 | က | 2 | 1 | 1 | 1 | 3 |
| Watermelon | I | NG | I | 1 | 12 | 5 | 4 | က | I |

Adapted from J. F. Harrington and P. A. Minges, "Vegetable Seed Germination," California Agricultural Extension Mimeo Leaflet (1954). $NG = No \ germination; --- = not \ tested$

04 SEED REQUIREMENTS

TABLE 3.7. APPROXIMATE NUMBER OF SEEDS PER UNIT WEIGHT AND FIELD SEEDING RATES FOR TRADITIONAL PLANT DENSITIES

| - | | | |
|-------------------------------|-----------------|----------|--|
| | Seeds | Unit | Field Seeding |
| Vegetable | (no.) | Weight | (lb/acre) |
| A | 14,000,00,000 | 11. | 0.0 |
| Asparagus ² | 14,000-20,000 | lb lb | 2–3 60 |
| Bean, baby lima | 1,200–1,500 | | |
| Bean, Fordhook lima | 400–600 | lb | 85 |
| Bean, bush snap | 1,600-2,000 | lb | 75–90 |
| Bean, pole snap | 1,600-2,000 | lb | 20–45 |
| Beet | 24,000-26,000 | lb | 10–15 |
| Broad bean | 300-800 | lb | 60–80 |
| Broccoli ³ | 9,000 | OZ | 1/2-11/2 |
| Brussels sprouts ³ | 9,000 | OZ | ¹ / ₂ -1 ¹ / ₂ |
| Cabbage ³ | 9,000 | OZ | $\frac{1}{2}-1\frac{1}{2}$ |
| Cantaloupe ³ | 16,000-20,000 | lb | 2 |
| Cardoon | 11,000 | lb | 4-5 |
| Carrot | 300,000-400,000 | lb | 2-4 |
| Cauliflower ³ | 9,000 | oz | $\frac{1}{2}-1\frac{1}{2}$ |
| Celeriac | 72,000 | OZ | 1-2 |
| Celery ³ | 72,000 | oz | 1-2 |
| Chicory | 27,000 | oz | 3-5 |
| Chinese cabbage | 9,000 | oz | 1-2 |
| Collards | 9,000 | oz | 2-4 |
| Corn salad | 13,000 | oz | 10 |
| Cucumber | 15,000-16,000 | lb | 3-5 |
| Dandelion | 35,000 | oz | 2 |
| Eggplant ³ | 6,500 | oz | 2 |
| Endive | 25,000 | oz | 3-4 |
| Florence fennel | 7,000 | oz | 3 |
| Kale | 9,000 | OZ | 2–4 |
| Kohlrabi | 9,000 | oz | 3–5 |
| Leek ³ | 200,000 | lb | 4 |
| Lettuce, head ³ | 20,000-25,000 | OZ | 1–3 |
| Lettuce, leaf | 25,000-30,000 | OZ | 1–3 |
| , ioui | 20,000 00,000 | OL. | - 0 |

TABLE 3.7. APPROXIMATE NUMBER OF SEEDS PER UNIT WEIGHT AND FIELD SEEDING RATES FOR TRADITIONAL PLANT DENSITIES (Continued)

| Vegetable | Seeds (no.) | Unit Weight | Field Seeding ¹ (lb/acre) |
|-------------------------------------|-----------------|----------------|---|
| Mustard | 15,000 | OZ | 3–5 |
| New Zealand spinach | 5,600 | lb | 15 |
| Okra | 8,000 | lb | 6–8 |
| Onion, bulb ³ | 130,000 | lb | 3–4 |
| Onion, bunching | 180,000-200,000 | lb | 3-4 |
| Parsley | 250,000 | lb | 20-40 |
| Parsnip | 192,000 | lb | 3–5 |
| Pea | 1,500-2,500 | lb | 80–250 |
| Pepper ³ | 4,200-4,600 | 0Z | 24 |
| Pumpkin | 1,500-4,000 | lb | 2-4 |
| Radish | 40,000-50,000 | lb | 10-20 |
| Roselle | 900-1,000 | oz | 3–5 |
| Rutabaga | 150,000-190,000 | lb | 1–2 |
| Salsify | 1,900 | OZ | 8–10 |
| Sorrel | 30,000 | oz | 2–3 |
| Southern pea | 3,600 | lb | 20-40 |
| Soybean | 4,000 | lb | 20-40 |
| Spinach | 45,000 | lb | 10-15 |
| Squash, summer | 3,500-4,500 | lb | 4–6 |
| Squash, winter | 1,600-4,000 | lb | 2–4 |
| Swiss chard | 25,000 | lb | 6–8 |
| Sweet corn, su, se | 1,800-2,500 | lb | 12–15 |
| Sweet corn, sh ₂ | 3,000-5,000 | lb | 12–15 |
| Tomato ³ | 10,000-12,000 | oz | ½-1 |
| Turnip | 150,000-200,000 | lb | 1–2 |
| Watermelon, small seed ³ | 8,000-10,000 | lb | 1–3 |
| Watermelon, large seed ³ | 3,000-5,000 | lb | 2–4 |

 $^{^1}$ Actual seeding rates are adjusted to desired plant populations, germination percentage of the seed lot, and weather conditions that influence germination.

²6-8 lbs/acre for crown production

 $^{^3}$ Transplants are used frequently instead of direct field seeding. See pages 62–64 for seeding rates for transplants.

05 PLANTING RATES FOR LARGE SEEDS

Weigh out a 1-oz sample of the seed lot and count the number of seeds. The following table gives the approximate pounds of seed per acre for certain between-row and in-row spacings of lima bean, pea, snap bean, and sweet corn. These are based on 100% germination. If the seed germinates only 90%, for example, then divide the pounds of seed by 0.90 to get the planting rate. Do the same with other germination percentages.

Example: 30 seeds/oz to be planted in 22-in. rows at 1-in. spacing between seeds.

$$\frac{595}{0.90} = 661 \text{ lb/acre}$$

Only precision planting equipment begins to approach as exact a job of spacing as this table indicates. Moreover, field conditions such as soil structure, temperature, and moisture affect germination and final stand.

TABLE 3.8. PLANTING RATES FOR LARGE SEEDS

| | | | 9 | | 86 | 74 | 90 | 48 | 43 | 37 | 33 | 30 | 22 | 25 | 53 | 52 | 50 |
|----------------------------|----|------------------------------------|----|-----------------------|------|-------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | | | | | | | 72 (| | | | | | | | | | |
| | | | 3 | | 119 | | | | | | | | | | | | |
| | 22 | | 4 | | 149 | 112 | 90 | 73 | 64 | 56 | 50 | 45 | 40 | 37 | 34 | 32 | 30 |
| | 63 | | က | | 198 | 148 | 120 | 97 | 85 | 74 | 99 | 09 | 54 | 49 | 46 | 43 | 40 |
| | | | 23 | | 298 | 223 | 180 | 145 | 128 | 112 | 66 | 90 | 80 | 74 | 69 | 64 | 09 |
| | | | 1 | | 595 | 446 | 361 | 289 | 256 | 223 | 198 | 181 | 161 | 148 | 138 | 128 | 119 |
| | | | 9 | | 109 | 85 | 99 | 53 | 47 | 41 | 37 | 33 | 30 | 27 | 25 | 24 | 22 |
| | | (in.) | ro | cre) | 131 | 66 | 79 | 64 | 99 | 49 | 44 | 39 | 35 | 33 | 31 | 28 | 56 |
| Spacing Between Rows (in.) | | Spacing Between Seeds in Row (in.) | 4 | Seed Needed (lb/acre) | 164 | 123 | 66 | 80 | 20 | 62 | 55 | 20 | 4 | 40 | 38 | 35 | 33 |
| n Rou | 20 | eeds in | က | Teeded | 218 | 163 | 132 | 901 | 94 | 85 | 73 | 99 | 29 | 54 | 51 | 47 | 44 |
| Ветше | | een S | 2 | Seed N | • | 246 | | | | | | | | | | | |
| icing l | | g Betu | 1 | 02 | | 491 2 | | | | | | | | | | | |
| Spc | | acing | 9 | | 21 6 | | 74 3 | | | | | | | | | | |
| | | S_{I} | • | | _ | | | | | | | | | | | | |
| | | | 3 | | 146 | 110 | 88 | 26 | 65 | 54 | 48 | 45 | 40 | 36 | 34 | 30 | 28 |
| | 18 | | 4 | | 182 | 136 | 110 | 90 | 78 | 89 | 09 | 54 | 20 | 45 | 42 | 38 | 36 |
| | Ĥ | | က | | 242 | 182 | 146 | 118 | 104 | 90 | 85 | 72 | 99 | 09 | 99 | 52 | 49 |
| | | | 23 | | 364 | 273 | 220 | 178 | 156 | 136 | 120 | 108 | 66 | 90 | 84 | 78 | 73 |
| | | | П | | 726 | 545 | 440 | 354 | 312 | 272 | 242 | 216 | 198 | 180 | 168 | 156 | 146 |
| | | | Ž | of Seeds/oz | 30 | 40 | 50 | 09 | 70 | 80 | 06 | 100 | 110 | 120 | 130 | 140 | 150 |

Spacing Between Rows (in.)

| | | 9 | | 61 | 45 | 37 | 53 | 56 | 23 | 20 | 19 | 17 | 15 | 14 | 13 | 12 |
|----|---|---------|-----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | | 5 | | 73 | 55 | 44 | 38 | 31 | 27 | 24 | 21 | 20 | 18 | 17 | 15 | 14 |
| • | | 4 | | 91 | 89 | 55 | 45 | 39 | 34 | 30 | 27 | 25 | 23 | 21 | 19 | 18 |
| 36 | | 3 | | 121 | 91 | 73 | 59 | 52 | 45 | 41 | 37 | 33 | 30 | 28 | 56 | 24 |
| | | 2 | | 182 | 136 | 110 | 88 | 78 | 89 | 09 | 54 | 49 | 45 | 42 | 39 | 37 |
| | | 1 | | 363 | 272 | 220 | 177 | 156 | 136 | 121 | 108 | 66 | 90 | 84 | 78 | 73 |
| | | 9 | | 73 | 54 | 44 | 35 | 31 | 27 | 25 | 25 | 20 | 18 | 17 | 16 | 15 |
| | , (in.) | 5 | acre) | 88 | 99 | 53 | 43 | 38 | 33 | 29 | 27 | 24 | 22 | 20 | 19 | 18 |
|) | in Rou | 4 | Seed Needed (lb/acre) | 109 | 85 | 99 | 29 | 47 | 41 | 37 | 33 | 30 | 27 | 25 | 23 | 22 |
| 30 | Seeds 1 | Seeds 3 | Neede | 146 | 106 | 88 | 71 | 63 | 53 | 49 | 44 | 40 | 36 | 34 | 32 | 53 |
| | 30 — ——————————————————————————————————— | 2 | \mathbf{Seed} | 219 | 164 | 132 | 106 | 94 | 85 | 73 | 29 | 09 | 54 | 51 | 47 | 44 |
| | ng Bet | 1 | | 437 | 328 | 265 | 212 | 188 | 164 | 146 | 131 | 119 | 108 | 101 | 94 | 88 |
| | Spaci | 9 | | 91 | 89 | 55 | 44 | 33 | 34 | 30 | 28 | 25 | 23 | 21 | 20 | 18 |
| | | 5 | | 109 | 85 | 99 | 22 | 47 | 41 | 36 | 32 | 30 | 27 | 25 | 23 | 22 |
| 4 | | 4 | | 136 | 102 | 85 | 29 | 59 | 51 | 45 | 40 | 37 | 34 | 32 | 29 | 27 |
| 24 | | 3 | | 182 | 136 | 110 | 88 | 78 | 89 | 61 | 55 | 49 | 45 | 42 | 39 | 38 |
| | | 2 | | 273 | 204 | 165 | 133 | 117 | 102 | 90 | 81 | 74 | 89 | 63 | 58 | 22 |
| | | 1 | | 545 | 408 | 330 | 265 | 234 | 204 | 181 | 162 | 148 | 135 | 126 | 117 | 109 |
| | | Z | of Seeds/oz | 30 | 40 | 20 | 09 | 70 | 80 | 06 | 100 | 110 | 120 | 130 | 140 | 150 |

06 SPACING OF VEGETABLES

SPACING OF VEGETABLES AND PLANT POPULATIONS

Spacing for vegetables is determined by the equipment used to plant, maintain, and harvest the crop as well as by the area required for growth of the plant without undue competition from neighboring plants. Previously, row spacings were dictated almost entirely by the space requirement of cultivating equipment. Many of the traditional row spacings can be traced to the horse cultivator.

Modern herbicides have largely eliminated the need for extensive cultivation in many crops; thus, row spacings need not be related to cultivation equipment. Instead, the plant's space requirement can be used as the determining factor. In addition, profitability is related to maximum use of field growing space.

Invariably, plant populations increase when this approach is used. A more uniform product with a higher proportion of marketable vegetables as well as higher total yields result from the closer plant spacings. The term *high-density production* has been developed to describe vegetable spacings designed to satisfy the plant's space requirement.

TABLE 3.9. HIGH-DENSITY SPACING OF VEGETABLES

| Vegetable | Spacing (in.) | Plant Population (plants/acre) |
|-----------------------|---------------------------|--------------------------------|
| Bean, snap | 3	imes12 | 174,000 |
| Beet | 2	imes12 | 261,000 |
| Carrot | $1^{1\!/_{\!\!2}}	imes12$ | 349,000 |
| Cauliflower | 12 	imes 18 | 29,000 |
| Cabbage | 12 	imes 18 | 29,000 |
| Cucumber (processing) | 3	imes20 | 104,000 |
| Lettuce | 12 	imes 18 | 29,000 |
| Onion | 1 	imes 12 | 523,000 |

TABLE 3.10. TRADITIONAL PLANT AND ROW SPACINGS FOR VEGETABLES

| Vegetable | Between Plants in Row (in.) | Between Rows (in.) |
|-----------------------------|--------------------------------|-----------------------|
| | | |
| Artichoke | 48-72 | 84-96 |
| Asparagus | 9-15 | 48 - 72 |
| Bean, broad | 8-10 | 20-48 |
| Bean, snap | 2–4 | 18-36 |
| Bean, lima, bush | 3–6 | 18-36 |
| Bean, lima, pole | 8–12 | 36 - 48 |
| Bean, pole | 6–9 | 36 - 48 |
| Beet | 2–4 | 12 - 30 |
| Broccoli ¹ | 12-24 | 18-36 |
| Broccoli raab | 3–4 | 24 - 36 |
| Brussels sprouts | 18-24 | 24-40 |
| Cabbage ¹ | 12-24 | 24-36 |
| Cantaloupe and other melons | 12 | 60-84 |
| Cardoon | 12–18 | 30 – 42 |
| Carrot | 1–3 | 16 - 30 |
| Cauliflower ¹ | 14-24 | 24-36 |
| Celeriac | 4–6 | 24-36 |
| Celery | 6–12 | 18-40 |
| Chard, Swiss | 12-15 | 24 - 36 |
| Chervil | 6–10 | 12-18 |
| Chicory | 4–10 | 18-24 |
| Chinese cabbage | 10–18 | 18-36 |
| Chive | 12–18 | 24-36 |
| Collards | 12–24 | 24 - 36 |
| Corn | 8-12 | 30 – 42 |
| Cress | 2-4 | 12-18 |
| $Cucumber^1$ | 8-12 | 36 - 72 |
| Dandelion | 3–6 | 14-24 |
| Dasheen (taro) | 24-30 | 42-48 |
| Eggplant | 18–30 | 24-48 |
| Endive | 8-12 | 18-24 |
| Florence fennel | 4-12 | 24-42 |
| Garlic | 1–3 | 12-24 |
| Horseradish | 12–18 | 30-36 |

TABLE 3.10. TRADITIONAL PLANT AND ROW SPACINGS FOR VEGETABLES (Continued)

| Vegetable | Between Plants in Row (in.) | Between Rows (in.) |
|----------------------------|--------------------------------|-----------------------|
| Jerusalem artichoke | 15–18 | 42-48 |
| Kale | 18-24 | 24 - 36 |
| Kohlrabi | 3–6 | 12 - 36 |
| Leek | 2–6 | 12 - 36 |
| Lettuce, cos | 10–14 | 16-24 |
| Lettuce, head ¹ | 10-15 | 16-24 |
| Lettuce, leaf | 8–12 | 12-24 |
| Mustard | 5-10 | 12 - 36 |
| New Zealand spinach | 10-20 | 36-60 |
| Okra | 8-24 | 42 - 60 |
| Onion | 1–4 | 16-24 |
| Parsley | 4–12 | 12 - 36 |
| Parsley, Hamburg | 1–3 | 18-36 |
| Parsnip | 2–4 | 18-36 |
| Pea | 1–3 | 24-48 |
| Pepper ¹ | 12–24 | 18-36 |
| Potato | 6–12 | 30-42 |
| Pumpkin | 36-60 | 72–96 |
| Radish | ¹ / ₂ -1 | 8–18 |
| Radish, storage type | 4–6 | 18–36 |
| Rhubarb | 24–48 | 36–60 |
| Roselle | 24–46 | 60-72 |
| Rutabaga | 5–8 | 18–36 |
| Salsify | 2–4 | 18–36 |
| Scolymus | 2–4 | 18–36 |
| Scorzonera | 2-4 | 18–36 |
| Shallot | 4–8 | 36–48 |
| Sorrel | ¹½-1 | 12–18 |
| Southern pea | 3–6 | 18-42 |
| Spinach | 2–6 | 12–36 |
| Squash, bush ¹ | 24–48 | 36–60 |
| Squash, vining | 36–96 | 72–96 |
| Strawberry ¹ | 10-24 | 24-64 |
| Sweet potato | 10-24 | 36–48 |
| oweer poraro | 10-10 | 30-40 |

TABLE 3.10. TRADITIONAL PLANT AND ROW SPACINGS FOR VEGETABLES (Continued)

| Vegetable | Between Plants in Row (in.) | Between Rows (in.) |
|--------------------|--------------------------------|-----------------------|
| Tomato, flat | 18–48 | 36–60 |
| Tomato, staked | 12–24 | 36-48 |
| Tomato, processing | 2–10 | 42-60 |
| Turnip | 2–6 | 12 - 36 |
| Turnip greens | 1–4 | 6-12 |
| Watercress | 1–3 | 6-12 |
| Watermelon | 24–36 | 72–96 |

 $^{^{\}rm l}$ Some crops can be grown double-row fashion on polyethylene mulched beds with 10–20 in. between rows.

TABLE 3.11. LENGTH OF ROW PER ACRE AT VARIOUS ROW SPACINGS

| Distance Between Rows (in.) | Row Length (ft/acre) | Distance Between Rows (in.) | Row Length (ft/acre) |
|-----------------------------------|----------------------|-----------------------------------|-------------------------|
| 6 | 87,120 | 40 | 13,068 |
| 12 | 43,560 | 42 | 12,445 |
| 15 | 34,848 | 48 | 10,890 |
| 18 | 29,040 | 60 | 8,712 |
| 20 | 26,136 | 72 | 7,260 |
| 21 | 24,891 | 84 | 6,223 |
| 24 | 21,780 | 96 | 5,445 |
| 30 | 17,424 | 108 | 4,840 |
| 36 | 14,520 | 120 | 4,356 |

TABLE 3.12. NUMBER OF PLANTS PER ACRE AT VARIOUS SPACINGS

In order to obtain other spacings, divide 43,560, the number of square feet per acre, by the product of the between-rows and in-the-row spacings, each expressed as feet—that is, 43,560 divided by 0.75 (36 \times 3 in. or 3 \times 0.25 ft) = 58,080.

| Spacing | | Spacing | | Spacing | |
|----------------|---------|----------------|--------|--------------|--------|
| (in.) | Plants | (in.) | Plants | (ft) | Plants |
| | | | | | |
| 12 	imes 1 | 522,720 | 30 	imes 3 | 69,696 | 6 	imes 1 | 7,260 |
| 12×3 | 174,240 | 30×6 | 34,848 | 6×2 | 3,630 |
| 12 	imes 6 | 87,120 | 30 	imes 12 | 17,424 | 6×3 | 2,420 |
| 12 	imes 12 | 43,560 | 30 	imes 15 | 13,939 | 6 	imes 4 | 1,815 |
| | , | 30×18 | 11,616 | 6 	imes 5 | 1,452 |
| $15^1 	imes 1$ | 418,176 | 30 	imes 24 | 8,712 | 6 	imes 6 | 1,210 |
| 15 	imes 3 | 139,392 | | - , - | | , - |
| 15 	imes 6 | 69,696 | 36 	imes 3 | 58,080 | 7 	imes 1 | 6,223 |
| 15 	imes 12 | 34,848 | 36 	imes 6 | 29,040 | 7 	imes 2 | 3,111 |
| | ŕ | 36 	imes 12 | 14,520 | 7 	imes 3 | 2,074 |
| $18^1 	imes 3$ | 116,160 | 36 	imes 18 | 9,680 | 7 	imes 4 | 1,556 |
| 18 	imes 6 | 58,080 | 36 	imes 24 | 7,260 | 7 	imes 5 | 1,244 |
| 18 	imes 12 | 29,040 | 36 	imes 36 | 4,840 | 7 	imes 6 | 1,037 |
| 18 	imes 14 | 24,891 | | | 7 	imes 7 | 889 |
| 18×18 | 19,360 | 40 	imes 6 | 26,136 | | |
| | | 40 	imes 12 | 13,068 | 8 	imes 1 | 5,445 |
| $20^1 	imes 3$ | 104,544 | 40 	imes 18 | 8,712 | 8 	imes 2 | 2,722 |
| 20 	imes 6 | 52,272 | 40 	imes 24 | 6,534 | 8 	imes 3 | 1,815 |
| 20 	imes 12 | 26,136 | | | 8 	imes 4 | 1,361 |
| 20 	imes 14 | 22,402 | 42 	imes 6 | 24,891 | 8 	imes 5 | 1,089 |
| 20 	imes 18 | 17,424 | 42 	imes 12 | 12,445 | 8 	imes 6 | 907 |
| | | 42 	imes 18 | 8,297 | 8×8 | 680 |
| $21^1 	imes 3$ | 99,564 | 42 	imes 24 | 6,223 | | |
| 21 	imes 6 | 49,782 | 42 	imes 36 | 4,148 | 10 	imes 2 | 2,178 |
| 21 	imes 12 | 24,891 | | | 10 	imes 4 | 1,089 |
| 21 	imes 14 | 21,336 | 48 	imes 6 | 21,780 | 10 	imes 6 | 726 |
| 21 	imes 18 | 16,594 | 48 	imes 12 | 10,890 | 10 	imes 8 | 544 |
| | | 48 	imes 18 | 7,260 | 10 	imes 10 | 435 |
| 24 	imes 3 | 87,120 | 48 	imes 24 | 5,445 | | |

TABLE 3.12. NUMBER OF PLANTS PER ACRE AT VARIOUS SPACINGS (Continued)

| Spacing (in.) | Plants | Spacing (in.) | Plants | Spacing (ft) | Plants |
|---------------------------------|------------|----------------|--------|--------------|--------|
| 24×6 | 43,560 | 48 	imes 36 | 3,630 | | |
| 24×0 24×12 | 21,780 | 48×48 | 2,722 | | |
| 24×12 24×18 | , | 40 ^ 40 | 2,122 | | |
| 24×18 | $14,\!520$ | | | | |
| 24 	imes 24 | 10,890 | 60 	imes 12 | 8,712 | | |
| | | 60×18 | 5,808 | | |
| | | 60 	imes 24 | 4,356 | | |
| | | 60 	imes 36 | 2,904 | | |
| | | 60 	imes 48 | 2,178 | | |
| | | 60×60 | 1,742 | | |
| | | | | | |

 $^{^{1}}$ Equivalent to double rows on beds at 30-, 36-, 40-, and 42-in. centers respectively.

07 PRECISION SEEDING

High-density plantings, high costs of hand thinning, and erratic performance of mechanical thinners have resulted in the development of precision seeding techniques. The success of precision seeding depends on having seeds with nearly 100% germination and on exact placement of each seed.

Some of the advantages of precision seeding are:

- Reduced seed costs. Only the seed that is needed is sown.
- Greater crop uniformity. Each seed is spaced equally, fewer harvests are necessary, and/or greater yield is obtained at harvest.
- Improved yields. Each plant has an equal chance to mature; yields can increase 20% to 50%.
- Improved plant stands. Seeds are dropped shorter distances, resulting in less scatter and a uniform depth of planting.
- Thinning can be reduced or eliminated.

Some precautions must be taken to ensure the proper performance of precision seeding equipment:

- 1. A fine, smooth seedbed is required for uniform seeding depth.
- 2. Seed must have high germination.
- 3. Seed must be uniform in size; this can be achieved by seed sizing or seed coating.
- 4. Seed must be of regular shape; irregular seeds such as carrot, lettuce, and onion must be coated for satisfactory precision seeding. Seed size is increased 2 to 5 times with clay or proprietary coatings.

Several types of equipment are available for precision seeding of vegetables.

Belt type—represented by the StanHay seeder. Circular holes punched in a belt accommodate the seed size. Holes are spaced along the belt at specified intervals. Coated seed usually improves the uniformity obtained with this type of seeder.

Plate type—represented by the John Deere 33 or Earth Way. Seeds drop into a notch in a horizontal plate and are transported to the drop point. The plate is vertical in the Earth Way and catches seed in a pocket in a plastic plate. Most spacing is achieved by gearing the rate of turn of the plate.

- Vacuum type—represented by the Gaspardo, Heath, Monosem, StanHay, and several other seeders. Seed is drawn against holes in a vertical plate and agitated to remove excess seed. Various spacings are achieved through a combination of gears and number of holes per plate. Coated seed should not be used in these planters.
- Spoon type—represented by the Nibex. Seed is scooped up out of a reservoir by small spoons (sized for the seed) and then carried to a drop shoot, where the spoon turns and drops the seed. Spacing is achieved by spoon number and gearing.
- Pneumatic type—represented by the International Harvester cyclo planter.
 Seed is held in place against a drum until the air pressure is broken.
 Then it drops in tubes and is blown to the soil. This planter is recommended only for larger vegetable seed.
- Grooved cylinder type—represented by the Gramor seeder. This seeder requires round seed or seed that is made round by coating. Seven seeds fall from a supply tube into a slot at the top of a metal case into a metal cylinder. The cylinder turns slowly. As it reaches the bottom of the case, the seed drops out of a diagonal slot. The seed is placed in desired increments by a combination of forward speed and turning rate. This planter can be used with seed as small as pepper seed, but it works best with coated seed.

Guidelines for Operation and Maintenance of Equipment

- Check the planter for proper operation and replace worn parts during the off season.
- 2. Thoroughly understand the contents of the manufacturer's manual.
- 3. Make certain that the operator is trained to use the equipment and check its performance.
- 4. Double-check settings to obtain desired spacing and depth.
- 5. Make a trial run before moving to the field.
- 6. Operate the equipment at the recommended tractor speed.
- Check the seed drop of each unit periodically during the planting operation.

Adapted in part from D. C. Sanders, "Precision Seeding for Vegetable Crops," North Carolina Cooperative Extension Service Publication HIL-36 (1997).

TABLE 3.13. NUMBER OF SEEDS PLANTED PER MINUTE AT VARIOUS SPEEDS AND SPACINGS¹

| Planter Speed (mph) | In-row Spacing (in.) | | | |
|---------------------|----------------------|-------|-------|-----|
| | 2 | 3 | 4 | 6 |
| 2.5 | 1,320 | 880 | 660 | 440 |
| 3.0 | 1,584 | 1,056 | 792 | 528 |
| 4.0 | 2,112 | 1,408 | 1,056 | 704 |
| 5.0 | 2,640 | 1,760 | 1,320 | 880 |

Adapted from Precision Planting Program, Asgrow Seed Co., Kalamazoo, Mich.

 $^{^{1}\}mathrm{For}$ most conditions, a planter speed of 2–3 mph results in the greatest precision.

08 SEED PRIMING

Seed priming is a physiology-based seed enhancement technique designed to improve the germination characteristics of seeds. Germination speed, uniformity, and seedling vigor are all improved by priming. These benefits are especially pronounced under adverse temperature and/or moisture conditions.

The commercial applications of seed priming have been expanding rapidly in recent years. Important vegetable crops now enhanced through priming include brassicas, carrot, celery, cucurbits, lettuce, onion, pepper, and tomato. More crop species are being added on an ongoing basis.

Priming is accomplished by partially hydrating seed and maintaining it under defined moisture, temperature, and aeration conditions for a prescribed period. In this state, the seed is metabolically active. In an optimally hydrated, metabolically active state, important germination steps can be accomplished within the seed. These include repair of membranes and/or genetic material, development of immature embryos, alteration of tissues covering the embryo, and destruction or removal of dormancy blocks.

At the conclusion of the process, the seed is redried to its storage moisture level. The gains made in priming are not lost during storage. Primed seed is physiologically closer to germination than nonprimed seed. When planted at a later date, primed seed starts at this advanced state and moves directly into the final stages of germination and growth.

There are several commercial methods of seed priming. All are based on the basic principles of hydrated seed physiology. They differ in the methods used to control hydration, aeration, temperature, and dehydration. The most important commercial priming methods include:

Liquid osmotic. In this approach, seed is bubbled in a solution of known osmotic concentration (accomplished with various salts or organic osmotic agents). The osmotic properties of the solution control water uptake by the seed. The bubbling is necessary to provide sufficient oxygen to keep the seed alive during the process. The temperature of the solution is controlled throughout the process. After priming is completed, the seeds are removed, washed, and dried.

Membrane and/or flat media osmotic. This method is a variation of liquid osmotic priming. With this method, the seed is placed on a porous membrane suspended on the surface of the osmotic solution. This method addresses some of the aeration concerns associated with liquid osmotic priming but is limited by practical considerations to smaller seed lots.

- Drum hydration. With this method, seeds are placed in a rotating drum and controlled quantities of water are sprayed onto the seed, bringing it to the desired moisture level. Drum rotation provides the necessary aeration to the seeds, and temperature and air flow are controlled throughout the process. After the priming period, the seed is dried by flushing air through the drum. Drum priming is a patented technology.
- Solid matrix priming (SMP). With the SMP method, water uptake is controlled by suspending seed in a defined medium (or matrix) of solids (organic and/or inorganic) of known water-holding properties. The seed and matrix compete for available water, coming to equilibrium at precisely the right point for priming to occur. Aeration and temperature are precisely controlled throughout the process. After the process is complete, the seed and matrix are separated. The seed is dried to its original moisture. The SMP method is a patented technology.

In maintaining processing conditions during priming, it is important to prevent the seed from progressing too far through the germination process. If germination is allowed to progress beyond the early stages, it is too late to return to a resting state. The seed is committed to growth and cannot be redried without damage and/or reduced shelf life.

Priming alters many basic characteristics of germination and seedling emergence, as indicated below:

- Germination speed. Primed seed has already accomplished the early stages of germination and begins growing much more rapidly. The total time required is cut approximately in half. This is especially important with slow-germinating species such as celery and carrot.
- Increased temperature range. Primed seed emerges under both cooler and warmer temperatures than unprimed seed. Generally, the temperature range is extended 5–8°F in both directions.
- More uniform emergence. The distribution of germination times within most seed lots is greatly reduced, resulting in improved uniformity.
- Germination at reduced seed water content. Primed seed germinates at a lower seed water content than unprimed seed.
- Control of dormancy mechanisms. In many cases, priming overcomes dormancy mechanisms that slow germination.
- Germination percentages. An increase in the germination percentage occurs in many instances with individual seed lots as a result of the priming process. The increase is generally due to repair of weak or abnormal seeds within the lot.

Considerations with Primed Seed

Shelf Life of Primed Seed

Shelf life is a complicated subject and is influenced by many factors. The most important factors are crop species, seed lot quality, seed moisture content in storage, transportation and storage conditions (especially temperature), the degree to which a lot is primed, and subsequent seed treatments (fungicides, film coating, pelleting).

Assuming proper transportation and storage conditions and no other complicating factors (such as coating), deterioration in seed lot performance is rarely experienced during the growing season for which a lot was primed (generally 4 months). In most cases (assuming the same qualifiers listed above), lot performance is maintained for much longer.

As storage time increases, the risk of loss also increases. Most lots are stable, but a percentage deteriorate rapidly. Not only is the priming effect lost, but generally a significant percentage of the lot dies. Screening methods to predict high-risk lots are needed. The results of research in this area are promising, but a usable method of predicting deterioration is not yet available.

Seed should be primed for planting during the immediate growing season only. Priming seed for planting in subsequent years is discouraged. In cases where primed seed must be held for extended periods, the seed should be retested before planting to assess whether or not deterioration occurred.

Treating, Coating, and Pelleting Primed Seed

The compatibility of primed seed with any subsequent seed treatment, coating, or pelleting must be determined on a case-by-case basis. The germination characteristics may be influenced. In some cases, priming is performed to improve the vigor of lots that would otherwise not tolerate the stress of coating or pelleting. In other cases, primed seeds may be more sensitive than unprimed seeds and experience deterioration. Combinations must be tested after priming, on a case-by-case basis, before other commercial treatments are performed.

Transport and Storage Conditions

Exposure to high temperatures, even for brief periods, can induce rapid deterioration of all seeds. The risk is greater with primed seeds. In storage and transport, it is important to maintain seeds that have been enhanced under dry, cool conditions (temperatures of 70°F or lower are recommended). Unfavorable conditions may negatively influence shelf life.

Adapted from John A. Eastin and John S. Vendeland. Kamterter Products, Inc., Lincoln, Neb. "Seed Priming" Presented at Florida Seed Association Seminar (1996), and C. Parera and D. Cantliffe, "Seed Priming," *Horticultural Reviews* 16 (1994):109–141.

09 VEGETATIVE PROPAGATION

TABLE 3.14. STORAGE OF PLANT PARTS USED FOR VEGETATIVE PROPAGATION

| Plant Part | Temperature (°F) | Relative Humidity (%) | Comments |
|-------------------|---|-----------------------------|---|
| Asparagus crowns | 30–32 | 85–90 | Roots may be trimmed to 8 in. Prevent heating and excessive drying. |
| Garlic bulbs | 50 | 50–65 | Fumigate for mites, if present. Hot-water-treat (120°F for 20 min) for control of stem and bulb nematode immediately before planting. |
| Horseradish roots | 32 | 85–90 | Pit storage is used in cold climates. |
| Onion sets | 32 | 70–75 | Sets may be cured naturally in the field, in trays, or artificially with warm, dry air. |
| Potato tubers | 36–40 (extended storage), 45–50 (short storage) | 90 | Cure at 60–65°F and 90–95% relative humidity for 10–14 days. Move to 60–65°F 10–14 days before planting. |
| Rhubarb crowns | 32–35 | 80–85 | Field storage is satisfactory in cold climates. |
| Strawberry plants | 30–32 | 85–90 | Store in crates lined with 1.5-mil polyethylene. |

TABLE 3.14. STORAGE OF PLANT PARTS USED FOR VEGETATIVE PROPAGATION (Continued)

| Plant Part | $Temperature \ (^{\circ}F)$ | Relative Humidity (%) | Comments |
|-----------------------|-----------------------------|-----------------------------|---|
| Sweet potato roots | 55–60 | 85–90 | Cure roots at 85°F and 85–90% relative humidity for 6–8 |
| Witloof chicory roots | 32 | 90–95 | days before storage. Prevent excessive drying. |

TABLE 3.15. FIELD REQUIREMENTS FOR VEGETATIVELY PROPAGATED CROPS

| Vegetable | Plant Parts | Quantity/acre ¹ | |
|---------------------|--------------------------|----------------------------|--|
| | | 007.1.001 | |
| Artichoke | Root sections | 807 - 1,261 | |
| Asparagus | Crowns | 5,808-10,890 | |
| Dasheen | Corms (2–5 oz) | 9–18 cwt | |
| Garlic | Cloves | $8-20~\mathrm{cwt}$ | |
| Jerusalem artichoke | Tubers (2 oz) | 10-12 cwt | |
| Horseradish | Root cuttings | 9,000-11,000 | |
| Onion | Sets | 5–10 cwt | |
| Potato | Tubers or tuber sections | 13-26 cwt | |
| Rhubarb | Crown divisions | 4,000-5,000 | |
| Strawberry | Plants | 6,000-50,000 | |
| Sweet potato | Roots for bedding | 5–6 cwt | |

¹Varies with field spacing, size of individual units, and vigor of stock.

TABLE 3.16. SEED POTATOES REQUIRED PER ACRE, WITH VARIOUS PLANTING DISTANCES AND SIZES OF SEED PIECE

| | | Seed Piece Weights | | | |
|------------------------------------|------|--------------------|-------------------|----------------------------------|------|
| Spacing of Rows and Seed Pieces | 1 oz | 1½ oz | $1\frac{1}{2}$ oz | 1 ³ / ₄ oz | 2 oz |
| Rows 30 in. Apart | | (Pour | nds of Seed / | Acre) | |
| nows 50 in. Apari | | | | | |
| 8-in. spacing | 1632 | 2040 | 2448 | 2856 | 3270 |
| 10-in. spacing | 1308 | 1638 | 1956 | 2286 | 2614 |
| 12-in. spacing | 1089 | 1361 | 1632 | 1908 | 2178 |
| 14-in. spacing | 936 | 1164 | 1398 | 1632 | 1868 |
| 16-in. spacing | 816 | 1020 | 1224 | 1428 | 1632 |
| Rows 32 in. Apart | | | | | |
| 8-in. spacing | 1530 | 1914 | 2298 | 2682 | 3066 |
| 10-in. spacing | 1224 | 1530 | 1836 | 2142 | 2448 |
| 12-in. spacing | 1020 | 1278 | 1536 | 1788 | 2040 |
| 14-in. spacing | 876 | 1092 | 1314 | 1530 | 1752 |
| 16-in. spacing | 768 | 960 | 1152 | 1344 | 1536 |
| Rows 34 in. Apart | | | | | |
| 8-in. spacing | 1440 | 1800 | 2160 | 2520 | 2880 |
| 10-in. spacing | 1152 | 1440 | 1728 | 2016 | 2304 |
| 12-in. spacing | 960 | 1200 | 1440 | 1680 | 1920 |
| 14-in. spacing | 822 | 1026 | 1236 | 1440 | 1644 |
| 16-in. spacing | 720 | 900 | 1080 | 1260 | 1440 |
| Rows 36 in. Apart | | | | | |
| 8-in. spacing | 1362 | 1704 | 2040 | 2382 | 2724 |
| 10-in. spacing | 1086 | 1362 | 1632 | 1902 | 2178 |
| 12-in. spacing | 906 | 1134 | 1362 | 1590 | 1812 |
| 14-in. spacing | 780 | 972 | 1164 | 1362 | 1554 |
| 16-in. spacing | 678 | 852 | 1020 | 1188 | 1362 |
| 18-in. spacing | 606 | 756 | 906 | 1056 | 1212 |

TABLE 3.16. SEED POTATOES REQUIRED PER ACRE, WITH VARIOUS PLANTING DISTANCES AND SIZES OF SEED PIECE

| | | Seed Piece Weights | | | | |
|------------------------------------|------|--------------------|-------|----------------------------------|------|--|
| Spacing of Rows and Seed Pieces | 1 oz | 1½ oz | 1½ oz | 1 ³ / ₄ oz | 2 oz | |
| Rows 42 in. Apart | | | | | | |
| 18-in. spacing | 516 | 648 | 780 | 906 | 1038 | |
| 24-in. spacing | 390 | 486 | 582 | 678 | 780 | |
| 30-in. spacing | 312 | 390 | 468 | 546 | 624 | |
| 36-in. spacing | 258 | 324 | 390 | 456 | 516 | |
| Rows 48 in. Apart | | | | | | |
| 18-in. spacing | 456 | 570 | 678 | 792 | 906 | |
| 24-in. spacing | 342 | 426 | 510 | 594 | 678 | |
| 30-in. spacing | 270 | 342 | 408 | 474 | 546 | |
| 36-in. spacing | 228 | 282 | 342 | 396 | 456 | |

10 POLYETHYLENE MULCHES

Polyethylene mulch has been used commercially on vegetables since the early 1960s. Currently, it is used on thousands of acres of vegetables in the United States. Florida and California lead in use, with about 100,000 acres of mulched vegetables in each state.

Types of Mulch

Basically, three major colors of mulch are used commercially: black, clear, and white (or white-on-black). Black mulch is used most widely because it suppresses weed growth, resulting in less chemical usage. Further, it is useful for cool seasons because it warms the soil by contact. Clear polyethylene is used widely in the northern United States because it promotes warmer soil temperatures (by the greenhouse effect) than does black mulch. Clear mulch requires use of labeled fumigants or herbicides underneath to prevent weed growth. White or white-on-black mulch is used for fall crops established under hot summer conditions. Soils under white mulch or white-on-black mulch remain cooler because less radiant energy is absorbed by the mulch. Some growers create their own white mulch by painting the surface of black-mulched beds with white latex paint. There are some other specialized mulches, such as red or metallized mulch, used for specialized circumstances, such as weed control, plant growth regulation, and insect repelling. Films can be made of thinner gauge and high density compared with low-density polyethylenes.

Benefits of Mulch

- Increases early yields. The largest benefit from polyethylene mulch is the increase in soil temperature in the bed, which promotes faster crop development and earlier yields.
- Aids moisture retention. Mulch reduces evaporation from the bed soil surface. As a result, a more uniform soil moisture regime is maintained and the frequency of irrigation is reduced slightly. Irrigation is still mandatory for mulched crops so that the soil under the mulch doesn't dry out excessively. Tensiometers placed in the bed between plants can help indicate when irrigation is needed.
- Inhibits weed growth. Black and white-on-black mulches greatly inhibit light penetration to the soil. Therefore, weed seedlings cannot survive under the mulch. Nutgrass can still be a problem, however. The nuts provide

- enough energy for the young nutgrass to puncture the mulch and emerge. Other pests, such as soilborne pathogens, insects, and nematodes, are not reduced by most mulches. Some benefit has been shown from high temperatures under clear mulch (solarization). Currently, the best measure for nutgrass and pest control under the mulch is labeled fumigation.
- Reduces fertilizer leaching. Fertilizer placed in the bed under the mulch is less subject to leaching by rainfall. As a result, the fertilizer program is more efficient, and the potential exists for reducing traditional amounts of fertilizer. Heavy rainfall that floods the bed can still result in fertilizer leaching. This fertilizer can be replaced if the grower is using drip irrigation, or it can be replaced with a liquid fertilizer injection wheel.
- Decreases soil compaction. Mulch acts as a barrier to the action of rainfall, which can cause soil crusting, compaction, and erosion. Less compacted soil provides a better environment for seedling emergence and root growth.
- Protects fruits. Mulch reduces rain-splashed soil deposits on fruits. In addition, mulch reduces fruit rot caused by soil-inhabiting organisms because it provides a protective barrier between the fruit and the organisms.
- Aids fumigation. Mulches increase the effectiveness of soil fumigant chemicals. Acting as a barrier to gas escape, mulches help keep gaseous fumigants in the soil. Recently, virtually impermeable films (VIF) have been developed to help trap fumigants better and reduce amounts of fumigants needed.

Negative Aspects of Mulch

- Mulch removal and disposal. The biggest problems associated with mulch use are removal and disposal. Because most mulches are not biodegradable, they must be removed from the field after use. This usually involves some hand labor, although mulch lifting and removal machines are available. Some growers burn the mulch, but the buried edges still must be removed by hand. Disposal also presents a problem because of the quantity of waste generated.
- Specialized equipment. The mulch cultural system requires a small investment in specialized equipment, including a bed press, mulch layer, and mulch transplanter or plug-mix seeder. Vacuum seeders are also available for seeding through mulch. This equipment is inexpensive and easily obtained, and some can even be manufactured on the farm.

Mulch Application

Mulch is applied by machine for commercial operations. Machines that prepare beds, fertilize, fumigate, and mulch in separate operations or in combination are available. The best option is to complete all of these operations in one pass across the field. In general, all chemicals and fertilizers are applied to the soil before mulching. Nitrogen and potassium fertilizers can be injected through a drip irrigation system under the mulch.

When laying mulch, be sure the bed is pressed firmly and that the mulch is in tight contact with the bed. This helps transfer heat from mulch to bed and reduces flapping in the wind, which results in tears and blowing of mulch from the bed. The mulch layer should be adjusted so that the edges are buried sufficiently to prevent uplifting by wind.

Degradable Mulches

Degradable plastic mulches have many of the properties and provide the usual benefits of standard polyethylene mulches. One important difference is that degradable mulches begin to break down after the film has received a predetermined amount of ultraviolet (UV) light.

When a film has received sufficient UV light, it becomes brittle and develops cracks, tears, and holes. Small sections of film may tear off and be blown around by the wind. Finally, the film breaks down into small flakes and disintegrates into the soil. The edges covered by the soil retain their strength and break down only after being disked to the surface, where they are exposed to UV light.

The use of long-lasting degradable mulches formulated for long-season crops, such as peppers, results in some plastic residue fragments remaining in the soil for the next crop. This residue is primarily the edges of film that were covered with soil. Seeding early crops in a field that had a long-term, degradable mulch the previous season should be avoided. Most plastic fragments should break down and disappear into the soil by the end of the growing season after the mulch was used.

Factors affecting the time and rate of breakdown:

- The formulation and manufacturing of the film—that is, short-, intermediate-, or long-lasting film.
- Factors that influence the amount of UV light received by the mulch film and, thus, the breakdown include the growth habit of the crop (vine or upright), the time of year the film is applied, the time between application and planting, crop vigor, and double- or single-

- row planting. Weed growth, mowing off the crop, and length of time the mulch is left in the field after harvest also influence time and extent of breakdown.
- High temperatures can increase the rate of breakdown, and wind can rapidly enlarge tears and holes in film that is breaking down.
- Other factors, including depressions in the bed, footprints, animal and tire tracks, trickle irrigation tubes under the film, and stress on the plastic resulting from making holes for plants and planting, all weaken the film and increase the rate of breakdown.

Suggestions for using degradable mulches:

- Select the proper mulch formulation for the crop. Consult the company representative.
- Make uniform beds, free from depressions and footprints. Apply long-term mulches 1–2 weeks before planting. This allows the mulch to receive UV light and initiate the breakdown process. Apply short-duration films a few days to immediately before planting.
- Minimize damage to the film and avoid unnecessary footprints, especially during planting and early in the growing season.
- Maintain clean weed control between mulch strips. Shading from weed growth can slow the rate of mulch breakdown.
- Lift the soil-covered edges before final harvest or as soon as possible after harvest. This exposes some of the covered edges to UV light and starts the breakdown process.
- Mow down crop immediately after the last harvest to allow UV light to continue the breakdown process.
- When film is brittle, disk the beds. Then, angle or cross-disk to break the mulch (especially the edges) into small fragments.
- Plant a cover crop to trap larger fragments and prevent them from blowing around. Plant a border strip of a tall-growing grass around the field to prevent fragments from blowing into neighboring areas.

Adapted from G. J. Hochmuth, R.C. Hochmuth, and S. M. Olson, "Polyethylene Mulching for Early Vegetable Production in North Florida," Florida Cooperative Extension Service Circular 805 (2001), http://edis.ifas.ufl.edu/CV213, E. R. Kee, P. Mulrooney, D. Caron, M. VanGessel, and J. Whalen, "Commercial Vegetable Production," Delaware Cooperative Extension Bulletin 137 (2005); W. L. Schrader, "Plasticulture in California," Publ. 8016 (2001), http://anrcatalog.ucdavis.edu, and The Center for Plasticulture at Penn State, http://plasticulture.cas.psu.edu.

11 ROW COVERS

Row covers have been used for many years for early growth enhancement of certain vegetables in a few production areas such as San Diego County, California. New materials and methods have been developed recently that make the use of row covers a viable production practice wherever vegetables are seeded or transplanted when temperatures are below optimum and early production is desired. Row covers, when properly used, result in earlier harvest and, perhaps, greater total production. There are two general types of row covers—supported and floating; many variations of the row cover concept are possible, depending on the needs of the individual grower. Row covers generally work best when used in conjunction with black polyethylene-mulched rows or beds.

Supported Row Covers

Clear polyethylene, 5-6 ft wide and $1-1\frac{1}{2}$ mils thick, is the most convenient material to use and is generally used just once. Slitted row covers have slits 5 in. long and 34 in. apart in two rows. The slits, arranged at the upper sides of the constructed supported row cover, provide ventilation; otherwise the cover would have to be manually opened and closed each day. Hoops of no. 8 or no. 9 wire are cut 63 in. long for 5-ft-wide polyethylene.

Hoops are installed over the polyethylene-mulched crop so that the center of the hoop is 14–16 in. above the row. The slitted row cover can be mechanically applied over the hoops with a high-clearance tractor and a modified mulch applicator.

Floating Row Covers

Floating row covers are made of spun-bonded polyester and polypropylene. The material is similar to the fabrics used in the clothing industry for interlining, interfacing, and other uses. It is white or off-white, porous to air and water, lightweight (0.6 oz/sq yd) and transmits about 80% of the light. The material comes in rolls 67 in. wide and 250–2,500 ft long. One-piece blankets are also available. With care, the spun-bonded fabrics can be used two to three or more times.

Immediately after planting (seeds or transplants), the spun-bonded fabric is laid directly over the row and the edges secured with soil, boards, bricks, or wire pins. Because the material is of such light weight, the plants push it up as they grow. Accordingly, enough slack should be provided to allow for the plants to reach maximum size during the time the material is left over the plants. For bean or tomato, about 12 in. slack should be left. For a crop

such as cucumber, 8 in. is sufficient. Supports should be considered in windy growing areas so plants are not damaged by cover abrasion.

Floating covers can be left over vegetables for 3–8 weeks, depending on the crop and the weather. For tomato and pepper, it can be left on for about 1 month but should be removed (at least partially) when the temperature under the covers reaches 86°F and is likely to remain that high for several hours.

Cantaloupe blossoms can withstand high temperatures, but the cover must be removed when the first female flowers appear so bees can begin pollination.

Frost Protection

Frost protection with slitted and floating covers is not as good as with solid plastic covers. A maximum of 3–4°F is all that can be expected, whereas with solid covers, frost protection of 5–7°F has been attained. Polypropylene floating row covers can be used for frost protection of vegetables and strawberries. Heavier covers 1.0–1.5 oz/yd can protect strawberries to 23–25°F. Row covers should not be viewed merely as a frost protection system but as a growth-intensifying system during cool spring weather. Therefore, do not attempt to plant very early and hope to be protected against heavy frosts. An earlier planting date of 10 days to 2 weeks is more reasonable. The purpose of row covers is to increase productivity through an economical increase of early and perhaps total production per unit area.

Adapted from O. S. Wells and J. B. Loy, "Row Covers for Intensive Vegetable Production," New Hampshire Cooperative Extension Service (1985); G. Hochmuth and R. Hochmuth, "Row Covers for Growth Enhancement," Florida Cooperative Extension Service Fact Sheet HS716 (2004), http://edis.ifas.ufl.edu/cv106.

W. L. Schrader, "Plasticulture in California," Publ. 8016 (2000), http://anrcatalog.ucdavis.edu; and The Center for Plasticulture at Penn State, http://plasticulture.cas.psu.edu.

12 WINDBREAKS

Windbreaks are important considerations in an intensive vegetable production system. Use of windbreaks can result in increased yield and earlier crop production.

Young plants are most susceptible to wind damage and sand blasting. Rye or other tall-growing grass strips between rows can provide protection from wind and windborne sand. Windbreaks can improve early plant growth and earlier crop production, particularly with melons, cucumbers, squash, peppers, eggplant, tomatoes, and okra.

A major benefit of a windbreak is improved use of moisture. Reducing the wind speed reaching the crop reduces both direct evaporation from the soil and the moisture transpired by the crop. This moisture advantage also improves conditions for seed germination. Seeds germinate more rapidly, and young plants establish root systems more quickly. Improved moisture conditions continue to enhance crop growth and development throughout the growing season.

The type and height of the windbreak determine its effect. Windbreaks can be living or nonliving. Rye strips are suggested for intensive vegetable production based on economics. In general, windbreaks should be as close as

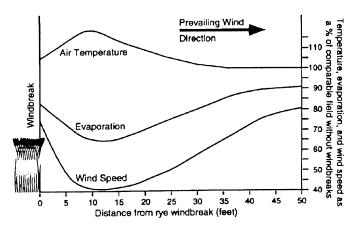


Figure 3.1. Air temperature, evaporation rate, and wind speed changes with distance from windbreak. Variables are expressed as percent of their level if the windbreak was not present.

economically viable—for example, every three or four beds of melons. The windbreak should be planted perpendicular to the prevailing wind direction. Rye strips should be planted prior to the crop to be protected so as to obtain good plant establishment and to provide adequate time for plant growth prior to beginning the next production season. Fertilization and pest management of rye windbreaks may be necessary to encourage growth to the desired height.

Adapted from J. R. Schultheis, D. C. Sanders, and K. B. Perry, "Windbreaks and Drive Rows," in D. C. Sanders (ed.), A Guide to Intensive Vegetable Systems (North Carolina Cooperative Extension AG-502, 1993, 9, and from R. Rouse and L. Hodges, "Windbreaks," in W. Lamont (ed.), Production of Vegetables, Strawberries, and Cut Flowers Using Plasticulture, (Ithaca, N.Y.: NRAES, Cooperative Extension Service, 2004), 57–66.

Vegetable Production in High Tunnels

Growing vegetables in large, walk-in, plastic-covered structures is popular in many parts of the world and is becoming more popular in the United States. Benefits of vegetable production in high-tunnels include earlier and extended-season production, tunnels can be sited on field soil, protection from rain, reduced disease, and insect pressure, less costly system than greenhouses, and less technology required. Most vegetables can be grown in a high-tunnel but the most popular crops are melons, cucumber, tomato, pepper, strawberry, salad crops, and herbs. More information on high-tunnel production can be found at The Center for Plasticulture at Penn State cited below.

http://plasticulture.cas.psu.edu/H-tunnels.html

13 ADDITIONAL SOURCES OF INFORMATION ON PLASTICULTURE

- W. L. Schrader, "Plasticulture in California: Vegetable Production," University of California. Publ. 8016 (2000), http://anardatalog. ucdavis.edu.
- H. Taber and V. Lawson, "Melon Row Covers," Iowa State University, http://www.public.iastate.edu/~taber/Extension/Melon/melonrc.html.

The Center for Plasticulture at Penn State, http://plasticulture.cas.psu.edu.

J. Brandle and L. Hodges, "Field Windbreaks," University of Nebraska Cooperative Extension Service EC-00-1778x.

PART 4 SOILS AND FERTILIZERS

- 01 NUTRIENT BEST MANAGEMENT PRACTICES
- 02 ORGANIC MATTER
- 03 SOIL-IMPROVING CROPS
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01 NUTRIENT BEST MANAGEMENT PRACTICES (BMPs)

With the passage of the Federal Clean Water Act in 1972, states were required to assess the impact of nonpoint sources of pollution on surface and ground waters and to establish programs to minimize these sources of pollution. This Act also requires states to identify impaired water bodies and establish total maximum daily loads (TMDLs) for pollutants entering those water bodies. TMDLs are the maximum amounts of pollutants that can enter a water body and still allow it to meet its designated uses, such as swimming, potable water, fishing, etc. States have implemented various programs to address TMDLs. For example, Florida has adopted a best management practice (BMP) approach to addressing TMDLs whereby nutrient BMPs are adopted by state rule. The following definition of a BMP is taken from the Florida Department of Agriculture and Consumer Services handbook, Water Quality/Quantity Best Management Practices for Florida Vegetable and Agronomic Crops. BMPs are a practice or combination of practices determined by state agencies, based on research, field testing, and expert review, to be the most effective and practical on-location means, including economic and technical considerations, for improving water quality in agricultural and urban discharges. BMPs must be technically feasible, economically viable, socially acceptable, and based on sound science. Some states' programs involve incentive measures for adopting BMPs, such as cost-share for certain management practices on the farm, and other technical assistance. Agricultural producers who adopt approved BMPs, depending on the state and the program, may be "presumed to be in compliance" with state water quality standards and are eligible for costshare funds to implement certain BMPS on the farm. States designate agencies for implementing the BMP programs and for verifying that the BMPs are effective at reducing pollutant loads.

Some information on BMP programs can be found at:

- USDA Natural Resources Conservation Service field office technical guide, http://www.nrcs.usda.gov.
- Florida Department of Agriculture and Consumer Services Water Quality/Quantity Best Management Practices for Florida Vegetable and Agronomic Crops, http://www.floridaagwaterpolicy.com/PDFs/ BMPs/vegetable&agronomicCrops.pdf.
- Farming for Clean Water in South Carolina: A Handbook of Conservation Practices (S.C.: NRCS), http://www.sc.nrcs.usda.gov/pubs.html.

- T. K. Hartz, Efficient Nitrogen Management for Cool-season Vegetables (University of California Vegetable Research and Information Center), http://vric.ucdavis.edu/veginfo/topics/.
- G. Hochmuth, Nitrogen Management Practices for Vegetable Production in Florida, http://edis.ifas.ufl.edu/CV237.
- Maryland Nutrient Management Manual, http://www.mda.state.md.us/ resource_conservation/nutrient_management/manual/index.php.
- Irrigation Management Practices: Checklist for Oregon, http://biosys.bre.orst.edu/bre/docs/irrigation.htm.
- Nutrient and Pesticide Management (Pacific Northwest Regional Water Program), http://www.pnwwaterweb.com/National/nut_pest.htm.
- Nutrient Management: NRCS Conservation Practice Standard (Wis.), http://www.dnr.state.wi.us/org/water/wm/nps/rules/.

02 ORGANIC MATTER

FUNCTION OF ORGANIC MATTER IN SOIL

Rapid decomposition of fresh organic matter contributes most effectively to the physical condition of a soil. Plenty of moisture, nitrogen, and a warm temperature speed the rate of decomposition.

Organic matter serves as a source of energy for soil microorganisms and as a source of nutrients for plants. Organic matter holds the minerals absorbed from the soil against loss by leaching until they are released for plant uptake by the action of microorganisms. Bacteria thriving on the organic matter produce complex carbohydrates that cement soil particles into aggregates. Acids produced in the decomposition of organic matter may make available mineral nutrients of the soil to crop plants. The entrance and percolation of water into and through the soil are facilitated. This reduces losses of soil by erosion. Penetration of roots through the soil is improved by good structure brought about by the decomposition of organic matter. The water-holding capacity of sands and sandy soils may be increased by the incorporation of organic matter. Aggregation in heavy soils may improve drainage. It is seldom possible to make a large permanent increase in the organic matter content of a soil.

ORGANIC SOIL AMENDMENTS

Animal manures, sludges, and plant materials have been used commercially for decades for vegetable production. Today, society demands efficient use of natural materials, so recycling of wastes into agriculture is viewed as important. Many municipalities are producing solid waste materials that can be used on the farm as soil amendments and sources of nutrients for plants. The technology of compost production and utilization is still developing. One challenge for the grower is to locate compost sources that yield consistent chemical and physical qualities. Incompletely composted waste, sometimes called *green compost*, can reduce crop growth because nitrogen is *robbed*, or used by the microorganisms to decompose the organic matter in the compost. Growers contemplating use of soil amendments should thoroughly investigate the quality of the product, including testing for nutrient content.

ENVIRONMENTAL ASPECTS OF ORGANIC SOIL AMENDMENTS

Although the addition of organic matter, such as manures, to the soil can have beneficial effects on crop performance, there are some potential negative effects. As the nitrogen is released from the organic matter, it can be subject to leaching. Heavy applications of manure can contribute to groundwater pollution unless a crop is planted soon to utilize the nitrogen. This potential can be especially great in southern climates, where nitrogen release can be rapid and most nitrogen is released in the first season after application. Plastic mulch placed over the manured soil reduces the potential for nitrate leaching. In today's environmentally aware world, manures must be used carefully to manage the released nutrients. Growers contemplating using manures as soil amendment or crop nutrient source should have the manure tested for nutrient content. The results from such tests can help determine the best rate of application so that excess nutrients such as N or P are not available for leaching or losses to erosion.

$\begin{array}{c} 03 \\ \text{SOIL-IMPROVING CROPS} \end{array}$

TABLE 4.1. SEED REQUIREMENTS OF SOIL-IMPROVING CROPS AND AREAS OF ADAPTATION

| Soil-Improving Crops | Seed (lb/acre) | U.S. Area Where Crop Is Adapted |
|--------------------------------------|-------------------|------------------------------------|
| Winter Co | ver Crops | |
| Legumes | | |
| $Berseem\ (Trifolium\ alexandrinum)$ | 15 | West and southeast |
| Black medic (Medicago lupulina) | 15 | All |
| Black lupine (Lupinus hirsutus) | 70 | All |
| Clover | | |
| $Crimson\ (Trifolium\ incarnatum)$ | 15 | South and southeast |
| Bur, California (Medicago hispida) | 25 | South |
| Southern (M. arabica) unhulled | 100 | Southeast |
| Tifton (M. rigidula) unhulled | 100 | Southeast |
| Sour (Melilotus indica) | 20 | South |
| Sweet, hubam (Melilotus alba) | 20 | All |
| Fenugreek (Trigonella | 30 | Southwest |
| foenumgraecum) | | |
| Field pea (Pisum sativum) | | |
| Canada | 80 | All |
| Austrian winter | 70 | All |
| Horse bean (Vicia faba) | 100 | Southwest and southeast |
| Rough pea (Lathyrus hirsutus) | 60 | Southwest and southeast |
| Vetch | | |
| Bitter (Vicia ervilia) | 30 | West and southeast |
| Common (V. sativa) | 50 | West and southeast |
| Hairy (V. villosa) | 30 | All |
| Hungarian (V. pannonica) | 50 | West and southeast |
| Monantha (V. articulata) | 40 | West and southeast |
| Purple (V. bengalensis) | 40 | West and southeast |
| Smooth (V. villosa var. glabrescens) | 30 | All |
| Woollypod (V. dasycarpa) | 30 | Southeast |
| Nonlegumes | | |
| Barley (Hordeum vulgare) | 75 | All |
| Mustard (Brassica nigra) | 20 | All |
| Oat (Avena sativa) | 75 | All |

TABLE 4.1. SEED REQUIREMENTS OF SOIL-IMPROVING CROPS AND AREAS OF ADAPTATION (Continued)

| Soil-Improving Crops | Seed (lb/acre) | U.S. Area Where Crop is Adapted |
|---|-------------------|---------------------------------|
| Rape (Brassica napus) | 20 | All |
| Rye (Secale cereale) | 75 | All |
| Wheat (Triticum sativum) | 75 | All |
| Summer Co | over Crops | |
| Legumes | | |
| Alfalfa (Medicago sativa) | 20 | All |
| Beggarweed (Desmodium | 10 | Southeast |
| purpureum) | | |
| Clover | | |
| Alyce (Alysicarpus vaginalis) | 20 | Southeast |
| Crimson (Trifolium incartum) | 15 | Southeast |
| $\operatorname{Red}(T.\ pratense)$ | 10 | All |
| Cowpea (Vigna sinensis) | 90 | South and southwest |
| Hairy indigo (Indigofera hirsuta) | 10 | Southern tier |
| Lezpedeza | | |
| Common ($Lezpedeza \ striata$) | 25 | Southeast |
| Korean ($L. stipulacea$) | 20 | Southeast |
| Sesbania (Sesbania exaltata) | 30 | Southwest |
| Soybean (Glycine max) | 75 | All |
| Sweet clover, white (Melilotus alba) | 20 | All |
| Sweet clover (M. officinalis) | 20 | All |
| Velvet bean (Stizolobium deeringianum) | 100 | Southeast |
| Nonlegumes | | |
| Buckwheat (Fagopyrum esculentum) | 75 | All |
| Pearl millet (Pennisetum glaucum) | 25 | Southern and southeast |
| Sorghum, Hegari (Sorghum vulgare) | 40 | Western half |
| Sudan grass (Sorghum vulgare var. sudanese) | 25 | All |

Adapted from Growing Summer Cover Crops, USDA Farmer's Bulletin 2182 (1967); P. R. Henson and E. A. Hollowell, Winter Annual Legumes for the South, USDA Farmers Bulletin 2146 (1960); P. R. Miller, W. A. Williams, and B. A. Madson, Covercrops for California Agriculture, University of California Division of Agriculture and Natural Resources Publication 21471 (1989), and Cover Cropping in Vineyards: A Growers Handbook, University of California Publication 3338.

DECOMPOSITION OF SOIL-IMPROVING CROPS

The normal carbon-nitrogen (C:N) ratio in soils is about 10:1. Turning under organic matter alters this ratio because most organic matter is richer in carbon than in nitrogen. Unless the residue contains at least 1.5% nitrogen, the decomposing organisms will utilize soil nitrogen as the energy source for the decomposition process. Soil organisms can tie up as much as 25 lb nitrogen per acre from the soil in the process of decomposition of carbon-rich fresh organic matter.

A soil-improving crop should be fertilized adequately with nitrogen to increase the nitrogen content somewhat and improve later decomposition. Nitrogen may have to be added as the soil-improving crop is incorporated into the soil. This speeds the decomposition and prevents a temporary shortage of nitrogen for the succeeding vegetable crop.

As a general rule, about 20 lb nitrogen should be added for each ton of dry matter for a nonlegume green-manure crop.

TABLE 4.2. APPROXIMATE CARBON-TO-NITROGEN RATIOS OF COMMON ORGANIC MATERIALS

| Material | C:N Ratio |
|----------------------|-----------|
| Alfalfa | 12:1 |
| Sweet clover, young | 12:1 |
| Sweet clover, mature | 24:1 |
| Rotted manure | 20:1 |
| Oat straw | 75:1 |
| Corn stalks | 80:1 |
| Timothy straw | 80:1 |
| Sawdust | 300:1 |

04 MANURES

TYPICAL COMPOSITION OF MANURES

Manures vary greatly in their nutrient content. The kind of feed used, the percentage and type of litter or bedding, the moisture content, and the age and degree of decomposition or drying all affect the composition. Some nitrogen is lost in the process of producing commercially dried, pulverized manures. The following data are representative analyses from widely scattered reports.

TABLE 4.3. COMPOSITION OF MANURES

| | | Approximate Composition (% dry weight) | | |
|---------|----------------|--|----------------------------|-----------|
| Source | Dry Matter (%) | N | $\mathrm{P}_2\mathrm{O}_5$ | K_2O |
| Dairy | 15–25 | 0.6-2.1 | 0.7-1.1 | 2.4-3.6 |
| Feedlot | 20-40 | 1.0 - 2.5 | 0.9 - 1.6 | 2.4 - 3.6 |
| Horse | 15-25 | 1.7 - 3.0 | 0.7 - 1.2 | 1.2 - 2.2 |
| Poultry | 20-30 | 2.0 - 4.5 | 4.5 - 6.0 | 1.2 - 2.4 |
| Sheep | 25 - 35 | 3.0 - 4.0 | 1.2 - 1.6 | 3.0 - 4.0 |
| Swine | 20-30 | 3.0 - 4.0 | 0.4 - 0.6 | 0.5 - 1.0 |

TABLE 4.4. NITROGEN LOSSES FROM ANIMAL MANURE TO THE AIR BY METHOD OF APPLICATION

| Application Method | Type of Manure | Nitrogen Loss (%) ¹ |
|---------------------------------|-------------------|-----------------------------------|
| Broadcast without incorporation | Solid | 15-30 |
| | Liquid | 10-25 |
| Broadcast with incorporation | Solid | 1-5 |
| | Liquid | 1-5 |
| Injection (knifing) | Liquid | 0-2 |
| Irrigation | Liquid | 30–40 |

Adapted from D. E. Chaney, L. E. Drinkwater, and G. S. Pettygrove. *Organic Soil Amendments and Fertilizers*, University of California Division of Agriculture and Natural Resources Publication 21505 (1992).

TYPICAL COMPOSITION OF SOME ORGANIC FERTILIZER MATERIALS

Under most environments, the nutrients in organic materials become available to plants slowly. However, mineralization of nutrients in organic matter can be hastened under warm, humid conditions. For example, in Florida, most usable nitrogen can be made available from poultry manure during one season. There is considerable variation in nutrient content among samples of organic soil amendments. Commercial manure products should have a summary of the chemical analyses on the container. Growers should have any organic soil amendment tested for nutrient content so fertilization programs can be planned. The data below are representative of many analyses noted in the literature and in reports of state analytical laboratories.

¹ Loss within 3 days of application

TABLE 4.5. COMPOSITION OF ORGANIC MATERIALS

| | Percentage on a Dry Weight Basis | | | |
|--------------------------|----------------------------------|----------|--------|--|
| Organic Materials | N | P_2O_5 | K_2O | |
| Bat guano | 10.0 | 4.0 | 2.0 | |
| Blood | 13.0 | 2.0 | 1.0 | |
| Bone meal, raw | 3.0 | 22.0 | | |
| Bone meal, steamed | 1.0 | 15.0 | _ | |
| Castor bean meal | 5.5 | 2.0 | 1.0 | |
| Cottonseed meal | 6.6 | 3.0 | 1.5 | |
| Fish meal | 10.0 | 6.0 | _ | |
| Garbage tankage | 2.5 | 2.0 | 1.0 | |
| Peanut meal | 7.0 | 1.5 | 1.2 | |
| Sewage sludge | 1.5 | 1.3 | 0.4 | |
| Sewage sludge, activated | 6.0 | 3.0 | 0.2 | |
| Soybean meal | 7.0 | 1.2 | 1.5 | |
| Tankage | 7.0 | 10.0 | 1.5 | |

TABLE 4.6. COMPOSITION OF ORGANIC MATERIALS

Approximate Pounds per Ton of Dry Material

| Materials | Moisture (%) | N | P_2O_5 | $ m K_2O$ |
|------------------------|--------------|----|----------|-----------|
| Alfalfa hay | 10 | 50 | 11 | 50 |
| Alfalfa straw | 7 | 28 | 7 | 36 |
| Barley hay | 9 | 23 | 11 | 33 |
| Barley straw | 10 | 12 | 5 | 32 |
| Bean straw | 11 | 20 | 6 | 25 |
| Beggarweed hay | 9 | 50 | 12 | 56 |
| Buckwheat straw | 11 | 14 | 2 | 48 |
| Clover hay | | | | |
| Alyce | 11 | 35 | _ | |
| Bur | 8 | 60 | 21 | 70 |
| Crimson | 11 | 45 | 11 | 67 |
| Ladino | 12 | 60 | 13 | 67 |
| Sweet | 8 | 60 | 12 | 38 |
| Cowpea hay | 10 | 60 | 13 | 36 |
| Cowpea straw | 9 | 20 | 5 | 38 |
| Field pea hay | 11 | 28 | 11 | 30 |
| Field pea straw | 10 | 20 | 5 | 26 |
| Horse bean hay | 9 | 43 | _ | |
| Lezpedeza hay | 11 | 41 | 8 | 22 |
| Lezpedeza straw | 10 | 21 | _ | |
| Oat hay | 12 | 26 | 9 | 20 |
| Oat straw | 10 | 13 | 5 | 33 |
| Ryegrass hay | 11 | 26 | 11 | 25 |
| Rye hay | 9 | 21 | 8 | 25 |
| Rye straw | 7 | 11 | 4 | 22 |
| Sorghum stover, Hegari | 13 | 18 | 4 | _ |
| Soybean hay | 12 | 46 | 11 | 20 |
| Soybean straw | 11 | 13 | 6 | 15 |
| Sudan grass hay | 11 | 28 | 12 | 31 |
| Sweet corn fodder | 12 | 30 | 8 | 24 |
| Velvet bean hay | 7 | 50 | 11 | 53 |
| Vetch hay | | | | |
| Common | 11 | 43 | 15 | 53 |
| Hairy | 12 | 62 | 15 | 47 |

TABLE 4.6. COMPOSITION OF ORGANIC MATERIALS (Continued)

Approximate Pounds per Ton of Dry Material

| Materials | Moisture (%) | N | $\mathrm{P}_2\mathrm{O}_5$ | K_2O |
|-------------|--------------|----|----------------------------|--------|
| Wheat hay | 10 | 20 | 8 | 35 |
| Wheat straw | 8 | 12 | 3 | 19 |

Adapted from Morrison Feeds and Feeding (Ithaca, N.Y.: Morrison, 1948).

05 SOIL TEXTURE

The particles of a soil are classified by size into sand, silt, and clay.

TABLE 4.7. CLASSIFICATION OF SOIL-PARTICLE SIZES

| Soil Particle Size Classes (diameter, mm) | | | | | |
|---|-------------|--------------------|------------------------------|----|--|
| 2.0 | 0.02 | } | 0.002 | 0 | |
| Gravel | Sand | Silt | Cl | ay | |
| Particles visible with the naked eye | Particles v | isible under pe | Particles visi electron m | | |

SOIL TEXTURAL TRIANGLE

The percentage of sand, silt, and clay may be plotted on the diagram to determine the textural class of that soil.

 $\it Example:$ A soil containing 13% clay, 41% silt, and 46% sand would have a loam texture.

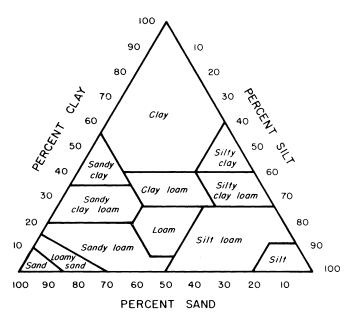


Figure 4.1. Soil textural triangle. From Soil Conservation Service, Soil Survey Manual, USDA Agricultural Handbook 18 (1951).

06 SOIL REACTION

RELATIVE TOLERANCE OF VEGETABLE CROPS TO SOIL ACIDITY

Vegetables in the slightly tolerant group can be grown successfully on soils that are on the alkaline side of neutrality. They do well up to pH 7.6 if there is no deficiency of essential nutrients. Vegetables in the very tolerant group grow satisfactorily at a soil pH as low as 5.0. For the most part, even the most tolerant crops grow better at pH 6.0–6.8 than in more acidic soils. Calcium, phosphorus, magnesium, and molybdenum are the nutrients most likely to be deficient in acidic soils.

TABLE 4.8. TOLERANCE OF VEGETABLES TO SOIL ACIDITY

| Slightly Tolerant | Moderately Tolerant | Very Tolerant |
|---------------------|---------------------|---------------|
| (pH 6.8–6.0) | (pH 6.8–5.5) | (pH 6.8–5.0) |
| Asparagus | Bean | Chicory |
| Beet | Bean, lima | Dandelion |
| Broccoli | Brussels sprouts | Endive |
| Cabbage | Carrot | Fennel |
| Cantaloupe | Collards | Potato |
| Cauliflower | Cucumber | Rhubarb |
| Celery | Eggplant | Shallot |
| Chard, Swiss | Garlic | Sorrel |
| Chinese cabbage | Gherkin | Sweet potato |
| Cress | Horseradish | Watermelon |
| Leek | Kale | |
| Lettuce | Kohlrabi | |
| New Zealand spinach | Mustard | |
| Okra | Parsley | |
| Onion | Pea | |
| Orach | Pepper | |
| Parsnip | Pumpkin | |
| Salsify | Radish | |
| Soybean | Rutabaga | |
| Spinach | Squash | |
| Watercress | Strawberry | |
| | Sweet corn | |
| | Tomato | |
| | Turnip | |

EFFECT OF SOIL REACTION ON AVAILABILITY OF NUTRIENTS

Soil reaction affects plants by influencing the availability of nutrients. Changes in soil reaction caused by liming or by the use of sulfur and acid-forming fertilizers may increase or decrease the supply of the nutrients available to the plants.

The general relationship between soil reaction and availability of plant nutrients in organic soils differs from that in mineral soils. The diagrams

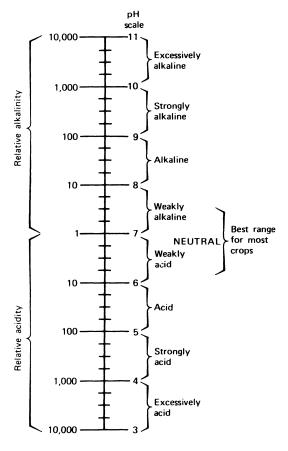


Figure 4.2. Relation Between pH, alkalinity, acidity, and plant growth.

depict nutrient availability for both mineral and organic soils. The width of the band indicates the availability of the nutrient. It does not indicate the actual amount present.

CORRECTION OF SOIL ACIDITY

Liming materials are used to change an unfavorable acidic soil reaction to a pH more favorable for crop production. However, soil types differ in their

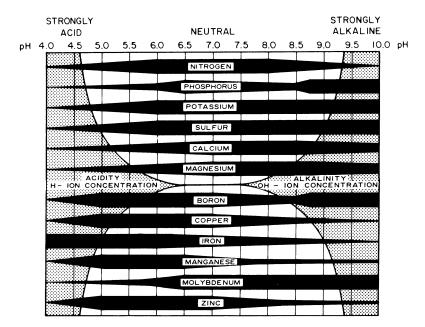


Figure 4.3. Influence of pH on the availability of plant nutrients in organic soils; widest parts of the shaded areas indicate maximum availability of each element.

Adapted from R. E. Lucas and J. F. Davis, "Relationships Between pH Values of Organic Soils and Availability of 12 Plant Nutrients," Soil Science 92(1961): 177–182.

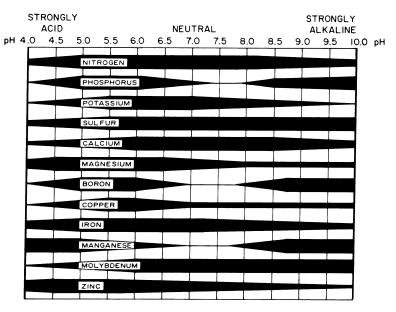


Figure 4.4. Influence of pH on the availability of plant nutrients in mineral soils; widest parts of the shaded areas indicate maximum availability of each element.

Adapted from L. B. Nelson (ed.), Changing Patterns in Fertilizer Use (Madison, Wis.: Soil Science Society of America, 1968).

response to liming, a property referred to as the soil's *pH buffering capacity*. Acidic soil reaction is caused by hydrogen ions present in the soil solution (active acidity) and attached to soil particles or organic matter (potential acidity). Active acidity can be neutralized rapidly, whereas potential acidity is neutralized over time as it is released. Soils vary in their relative content of these sources of acidity. Due to this complexity in soil pH, it is difficult to provide a rule of thumb for rates of liming materials. Most soil testing laboratories now use a lime requirement test to estimate the potential acidity and therefore provide a more accurate liming recommendation than could be done before. The lime requirement test treats the soil sample with a buffer solution to estimate the potential acidity, and thus provides a more accurate lime recommendation than can usually be obtained by treating the soil sample with water only. Soils with similar amounts of active acidity

might have different amounts of potential acidity and thus require different lime recommendations even though the rule-of-thumb approach might have given similar lime recommendations. Soils with large potential acidity (clays and mucks) require more lime than sandy soils with a similar water pH.

TABLE 4.9. COMMON LIMING MATERIALS

| Material | Chemical Formula | Pure CaCO ₃ Equivalent (%) | Liming Material (lb) Necessary to Equal 100 lb Limestone |
|---------------------|---------------------------------------|--|---|
| Burned lime | CaO | 150 | 64 |
| Hydrated lime | $Ca(OH)_2$ | 120 | 82 |
| Dolomitic limestone | CaCO ₃ , MgCO ₃ | 104 | 86 |
| Limestone | $CaCO_3$ | 95 | 100 |
| Marl | $CaCO_3$ | 95 | 100 |
| Shell, oyster, etc. | CaCO_3 | 95 | 100 |

TABLE 4.10. COMMON ACIDIFYING MATERIALS¹

| Material | Chemical Formula | Sulfur (%) | Acidifying Material (lb) Necessary to Equal 100 lb Soil Sulfur |
|-------------------------------------|------------------------------|------------|--|
| Soil sulfur | S | 99.0 | 100 |
| Sulfuric acid (98%) | $H_{2}SO_{4}$ | 32.0 | 306 |
| Sulfur dioxide | SO_{2} | 50.0 | 198 |
| Lime-sulfur solution (32° Baumé) | $CaS_x + water$ | 24.0 | 417 |
| Iron sulfate | $FeSO_4 \cdot 7H_2O$ | 11.5 | 896 |
| Aluminum sulfate | $\text{Al}_2(\text{SO}_4)_3$ | 14.4 | 694 |

 $^{^1\}mathrm{Certain}$ fertilizer materials also markedly increase soil acidity when used in large quantities (see page 165).

TABLE 4.11. APPROXIMATE QUANTITY OF SOIL SULFUR NEEDED TO INCREASE SOIL ACIDITY TO ABOUT pH 6.5

| Change in pH Desired | Sulfur (lb/acre) | | |
|----------------------|------------------|-------|-------|
| | Sands | Loams | Clays |
| 8.5–6.5 | 2,000 | 2,500 | 3,000 |
| 8.0-6.5 | 1,200 | 1,500 | 2,000 |
| 7.5 - 6.5 | 500 | 800 | 1,000 |
| 7.0 – 6.5 | 100 | 150 | 300 |

TABLE 4.12. EFFECT OF SOME FERTILIZER MATERIALS ON THE SOIL REACTION

| | | Pounds Limestone (CaCO ₃) | |
|--|--|--|---|
| Materials | N (%) | Per lb N | Per 100 lb Fertilizer Material |
| | | | Counteract ty Produced |
| Acidity-Forming Ammonium nitrate Monoammonium phosphate Ammonium phosphate sulfate Ammonium sulfate Anhydrous ammonia Aqua ammonia Aqua ammonia Diammonium phosphate Liquid phosphoric acid Urea | $\begin{array}{c} 33.5 \\ 11 \\ 16 \\ 21 \\ 82 \\ 24 \\ 30 \\ 16-18 \\ 52 \ (\mathrm{P_2O_5}) \\ 46 \end{array}$ | 1.80 5.35 5.35 5.35 1.80 1.80 1.80 1.80 Equivalent | 60 59 88 110 148 44 54 70 110 84 |
| Alkalinity-Forming Calcium cyanamide Calcium nitrate Potassium nitrate Sodium nitrate | 22 15.5 13 16 | 2.85 1.35 1.80 1.80 | 63 20 23 29 |
| Ammonium nitrate-lime Calcium sulfate (gypsum) Potassium chloride | Potassium sulfate Superphosphate | | |

Based on the method of W. H. Pierre, "Determination of Equivalent Acidity and Basicity of Fertilizers," $Industrial\ Engineering\ Chemical\ Analytical\ Edition,\ 5\ (1933):\ 229-234.$

RELATIVE SALT EFFECTS OF FERTILIZER MATERIALS ON THE SOIL SOLUTION

When fertilizer materials are placed close to seeds or plants, they may increase the osmotic pressure of the soil solution and cause injury to the crop. The term *salt index* refers to the effect of a material in relation to that produced by sodium nitrate, which is given a rating of 100. The *partial index* shows the relationships per unit (20 lb) of the actual nutrient supplied. Any material with a high salt index must be used with great care.

TABLE 4.13. SALT INDEX OF SEVERAL FERTILIZER MATERIALS

Partial Salt Index per Unit of Plant Material Salt Index Food Anhydrous ammonia 47.1 0.572 2.990 Ammonium nitrate 104.7 Ammonium nitrate-lime (Cal-Nitro) 61.1 2.982 Ammonium sulfate 69.0 3.253 Calcium carbonate (limestone) 4.7 0.083 Calcium nitrate 52.5 4.409 Calcium sulfate (gypsum) 8.1 0.247 1.614^{1} Diammonium phosphate 29.9 0.637^{2} Dolomite (calcium and magnesium 0.8 0.042 carbonates) 2.453^{1} Monoammonium phosphate 34.2 0.485^{2} Monocalcium phosphate 15.4 0.274Nitrogen solution, 37% 77.8 2.104 Potassium chloride, 50% 109.4 2.189 Potassium chloride, 60% 116.3 1.936 Potassium nitrate 73.6 5.336^{1} 1.580^{3} Potassium sulfate 46.1 0.853 Sodium chloride 153.8 2.899 Sodium nitrate 100.0 6.060 Sulfate of potash-magnesia 43.2 1.971 7.8 Superphosphate, 20% 0.390 Superphosphate, 45% 10.1 0.224 Urea 75.4 1.618

Adapted from L. F. Rader, L. M. White, and C. W. Whittaker, "The Salt Index: A Measure of the Effect of Fertilizers on the Concentration of the Soil Solution," $Soil\ Science\ 55\ (1943):201-218.$ $^{1}N\ ^{2}P_{2}O_{5}\ ^{3}K_{2}O$

TABLE 4.14. RELATIVE SALT TOLERANCE OF VEGETABLES

The indicated salt tolerances are based on growth rather than yield. With most crops, there is little difference in salt tolerance among varieties. Boron tolerances may vary depending on climate, soil condition, and crop variety.

| Vegetable | Maximum Soil Salinity Without Yield Loss (Threshold) (dS/m) | Decrease in Yield at Soil Salinities Above the Threshold (% per dS/m) |
|-------------------------|---|--|
| | (==== ================================= | (/- F / |
| Sensitive crops | | |
| Bean | 1.0 | 19 |
| Carrot | 1.0 | 14 |
| Strawberry | 1.0 | 33 |
| Onion | 1.2 | 16 |
| Moderately sensitive | 1.2 | 10 |
| Turnip | 0.9 | 9 |
| Radish | 1.2 | 13 |
| Lettuce | 1.3 | 13 |
| | 1.5 | 14 |
| Pepper | 1.5 1.5 | 14 11 |
| Sweet potato Broad bean | 1.6 | 10 |
| | | |
| Corn | 1.7 | 12 |
| Potato | 1.7 | 12 |
| Cabbage | 1.8 | 10 |
| Celery | 1.8 | 6 |
| Spinach | 2.0 | 8 |
| Cucumber | 2.5 | 13 |
| Tomato | 2.5 | 10 |
| Broccoli | 2.8 | 9 |
| Squash, scallop | 3.2 | 16 |
| Moderately tolerant | | |
| Beet | 4.0 | 9 |
| Squash, zucchini | 4.7 | 9 |

Adapted from E. V. Maas, "Crop Tolerance," California Agriculture (October 1984).

Note: 1 decisiemens per meter (dS/m) = 1 mmho/cm = approximately 640 mg/L salt

07 SALINITY

SOIL SALINITY

With an increase in soil salinity, plant roots extract water less easily from the soil solution. This situation is more critical under hot and dry than under humid conditions. High soil salinity may result also in toxic concentrations of ions in plants. Soil salinity is determined by finding the electrical conductivity of the soil saturation extract (ECe). The electrical conductivity is measured in millimhos per centimeter (mmho/cm). One mmho/cm is equivalent to 1 decisiemens per meter (dS/m) and, on the average, to 640 ppm salt.

TABLE 4.15. CROP RESPONSE TO SALINITY

| Salinity (expressed as ECe, mmho/cm, or dS/m) | Crop Responses |
|---|---|
| 0-2 2-4 4-8 8-16 Above 16 | Salinity effects mostly negligible. Yields of very sensitive crops may be restricted. Yields of many crops restricted. Only tolerant crops yield satisfactorily. Only a few very tolerant crops yield satisfactorily. |

 $\begin{tabular}{ll} Adapted from Leon Bernstein, Salt Tolerance of Plants, USDA Agricultural Information Bulletin 283 (1970). \end{tabular}$

08 FERTILIZERS

FERTILIZER DEFINITIONS

 $\it Grade$ or $\it analysis$ means the minimum guarantee of the percentage of total nitrogen (N), available phosphoric acid (P $_2{\rm O}_5$), and water-soluble potash (K $_2{\rm O}$) in the fertilizer.

Example: 20-0-20 or 5-15-5

Ratio is the grade reduced to its simplest terms.

Example: A 20-0-20 has a ratio of 1-0-1, as does a 10-0-10.

Formula shows the actual pound and percentage composition of the ingredients or compounds that are mixed to make up a ton of fertilizer.

An *open-formula mix* carries the formula as well as the grade on the tag attached to each bag.

Carrier, simple, or source is the material or compound in which a given plant nutrient is found or supplied.

Example: Ammonium nitrate and urea are sources or carriers that supply nitrogen.

Unit means 1% of 1 ton or 20 lb. On the basis of a ton, the units per ton are equal to the percentage composition or the pounds per 100 lb.

Example: Ammonium sulfate contains 21% nitrogen, or 21 lb nitrogen/100 lb, or 21 units nitrogen in a ton.

Primary nutrient refers to nitrogen, phosphorus, and potassium, which are used in considerable quantities by crops.

Secondary nutrient refers to calcium, magnesium, and sulfur, which are used in moderate quantities by crops.

Micronutrient, trace, or *minor element* refers to iron, boron, manganese, zinc, copper, and molybdenum, the essential plant nutrients used in relatively small quantities.

TABLE 4.16. APPROXIMATE COMPOSITION OF SOME CHEMICAL FERTILIZER MATERIALS $^{\scriptscriptstyle 1}$

| Fertilizer Material | Total Nitrogen (% N) | Available Phosphorus $(\% P_2O_5)$ | Water-soluble Potassium $(\% \text{ K}_2\text{O})$ |
|--|----------------------------|------------------------------------|--|
| Nitrogen | | | |
| Ammonium nitrate | 33.5 | _ | _ |
| Ammonium nitrate-lime (A-N-L, Cal-Nitro) | 20.5 | _ | _ |
| Monoammonium phosphate | 11.0 | 48.0 | _ |
| Ammonium phosphate-sulfate | 16.0 | 20.0 | _ |
| Ammonium sulfate | 21.0 | _ | _ |
| Anhydrous ammonia | 82.0 | _ | _ |
| Aqua ammonia | 20.0 | _ | _ |
| Calcium cyanamide | 21.0 | _ | _ |
| Calcium nitrate | 15.5 | _ | _ |
| Calcium ammonium nitrate | 17.0 | _ | _ |
| Diammonium phosphate | 16–18 | 46.0 - 48.0 | _ |
| Potassium nitrate | 13.0 | _ | 44.0 |
| Sodium nitrate | 16.0 | _ | _ |
| Urea | 46.0 | _ | _ |
| Urea formaldehyde | 38.0 | _ | _ |
| Phosphorus | | | |
| Phosphoric acid solution | _ | 52.0-54.0 | _ |
| Normal (single) superphosphate | _ | 18.0–20.0 | _ |
| Concentrated (triple or treble) superphosphate | _ | 45.0–46.0 | _ |
| Monopotassium phosphate | _ | 53.0 | _ |
| Potassium | | | |
| Potassium chloride | _ | _ | 60.0–62.0 |
| Potassium nitrate | 13.0 | _ | 44.0 |
| Potassium sulfate | _ | _ | 50.0-53.0 |
| Sulfate of potash-magnesia | _ | _ | 26.0 |
| Monopotassium phosphate | _ | _ | 34.0 |

¹See page 165 for effect of these materials on soil reaction.

TABLE 4.17. SOLUBILITY OF FERTILIZER MATERIALS

Solubility of fertilizer materials is an important factor in preparing starter solutions, foliar sprays, and solutions to be knifed into the soil or injected into an irrigation system. Hot water may be needed to dissolve the chemicals.

| Material | Solubility in Cold Water (lb/100 gal) |
|--|--|
| Primary Nutrients | |
| Ammonium nitrate | 984 |
| Ammonium sulfate | 592 |
| Calcium cyanamide | Decomposes |
| Calcium nitrate | 851 |
| Diammonium phosphate | 358 |
| Monoammonium phosphate | 192 |
| Potassium nitrate | 108 |
| Sodium nitrate | 608 |
| Superphosphate, single | 17 |
| Superphosphate, treble | 33 |
| Urea | 651 |
| Secondary Nutrients and Micronutrients | |
| Ammonium molybdate | Decomposes |
| Borax | 8 |
| Calcium chloride | 500 |
| Copper oxide | Insoluble |
| Copper sulfate | 183 |
| Ferrous sulfate | 242 |
| Magnesium sulfate | 592 |
| Manganese sulfate | 876 |
| Sodium chloride | 300 |
| Sodium molybdate | 467 |
| Zinc sulfate | 625 |

TABLE 4.18. AMOUNT OF CARRIERS NEEDED TO SUPPLY A CERTAIN AMOUNT OF NUTRIENT PER ACRE $^{\scriptscriptstyle 1}$

| | | Nutrients (lb/acre) | | | | | | |
|----------------------------|-----|---------------------|-------|------------|----------|-------|-------|-------|
| | 20 | 40 | 60 | 80 | 100 | 120 | 160 | 200 |
| Nutrient in Carrier (%) | | | (| Carriers : | Needed (| (lb) | | |
| 3 | 667 | 1,333 | 2,000 | | | | | |
| 4 | 500 | 1,000 | 1,500 | 2,000 | | | | |
| 5 | 400 | 800 | 1,200 | 1,600 | 2,000 | | | |
| 6 | 333 | 667 | 1,000 | 1,333 | 1,667 | 2,000 | | |
| 7 | 286 | 571 | 857 | 1,142 | 1,429 | 1,714 | | |
| 8 | 250 | 500 | 750 | 1,000 | 1,250 | 1,500 | 2,000 | |
| 9 | 222 | 444 | 667 | 889 | 1,111 | 1,333 | 1,778 | |
| 10 | 200 | 400 | 600 | 800 | 1,000 | 1,200 | 1,600 | 2,000 |
| 11 | 182 | 364 | 545 | 727 | 909 | 1,091 | 1,455 | 1,818 |
| 12 | 166 | 333 | 500 | 666 | 833 | 1,000 | 1,333 | 1,666 |
| 13 | 154 | 308 | 462 | 615 | 769 | 923 | 1,231 | 1,538 |
| 15 | 133 | 267 | 400 | 533 | 667 | 800 | 1,067 | 1,333 |
| 16 | 125 | 250 | 375 | 500 | 625 | 750 | 1,000 | 1,250 |
| 18 | 111 | 222 | 333 | 444 | 555 | 666 | 888 | 1,111 |
| 20 | 100 | 200 | 300 | 400 | 500 | 600 | 800 | 1,000 |
| 21 | 95 | 190 | 286 | 381 | 476 | 571 | 762 | 952 |
| 25 | 80 | 160 | 240 | 320 | 400 | 480 | 640 | 800 |
| 30 | 67 | 133 | 200 | 267 | 333 | 400 | 533 | 667 |
| 34 | 59 | 118 | 177 | 235 | 294 | 353 | 471 | 588 |
| 42 | 48 | 95 | 143 | 190 | 238 | 286 | 381 | 476 |
| 45 | 44 | 89 | 133 | 178 | 222 | 267 | 356 | 444 |
| 48 | 42 | 83 | 125 | 167 | 208 | 250 | 333 | 417 |
| 50 | 40 | 80 | 120 | 160 | 200 | 240 | 320 | 400 |
| 60 | 33 | 67 | 100 | 133 | 167 | 200 | 267 | 333 |

 $^{^{1}\}mathrm{This}$ table can be used in determining the acre rate for applying a material in order to supply a certain number of pounds of a nutrient.

Example: A carrier provides 34% of a nutrient. To get 200 lb of the nutrient, 588 lb of the material is needed, and for 60 lb of the nutrient, 177 lb of carrier is required.

TABLE 4.19. APPROXIMATE RATES OF MATERIALS TO PROVIDE CERTAIN QUANTITIES OF NITROGEN PER ACRE

| | N (lb/acre): | 15 | 30 | 45 | 60 | 75 | 100 |
|---|--------------|-----|--------|---------|-------|-------|------|
| Fertilizer Material | % N | M | ateria | al to A | Apply | (lb/a | cre) |
| Solids | | | | | | | |
| Ammonium nitrate | 33 | 45 | 90 | 135 | 180 | 225 | 300 |
| Ammonium phosphate (48% P_2O_5) | 11 | 135 | 270 | 410 | 545 | 680 | 910 |
| Ammonium phosphate-sulfate $(20\% P_2O_5)$ | 16 | 95 | 190 | 280 | 375 | 470 | 625 |
| Ammonium sulfate | 21 | 70 | 140 | 215 | 285 | 355 | 475 |
| Calcium nitrate | 15.5 | 95 | 195 | 290 | 390 | 485 | 645 |
| Potassium nitrate | 13 | 115 | 230 | 345 | 460 | 575 | 770 |
| Sodium nitrate | 16 | 95 | 190 | 280 | 375 | 470 | 625 |
| Urea | 46 | 35 | 65 | 100 | 130 | 165 | 215 |
| Liquids | | | | | | | |
| Anhydrous ammonia (approx. 5 lb/gal) ¹ | 82 | 20 | 35 | 55 | 75 | 90 | 120 |
| Aqua ammonium phosphate (24% P ₂ O ₅ ; approx. 10 lb/gal) | 8 | 190 | 375 | 560 | 750 | 940 | 1250 |
| Aqua ammonia (approx. 7½ lb/gal)¹ | 20 | 75 | 150 | 225 | 300 | 375 | 500 |
| Nitrogen solution (approx. 11 lb/gal) | 32 | 50 | 100 | 150 | 200 | 250 | 330 |

 $^{^1}$ To avoid burning, especially on alkaline soils, these materials must be placed deeper and farther away from the plant row than dry fertilizers are placed.

TABLE 4.20. RATES OF APPLICATION FOR SOME NITROGEN SOLUTIONS

Nitrogen Solution Needed (gal/acre)

22.6

24.0

25.4

26.8

28.2

31.1

33.9

36.7

39.6

42.4

56.5

20.5

21.8

23.1

24.4

25.6

28.2

30.8

33.3

35.9

38.5

51.3

Nitrogen (lb/acre) 21% Solution 32% Solution 41% Solution 20 8.9 5.6 5.1 25 6.4 11.1 7.1 30 13.3 8.5 7.7 35 15.6 9.9 9.0 40 17.8 11.3 10.3 45 20.0 12.7 11.5 50 22.2 14.1 12.8 55 24.4 15.5 14.1 26.7 60 16.5 15.4 65 28.9 18.4 16.7 70 31.1 17.9 19.8 75 33.3 21.2 19.2

Adapted from C. W. Gandt, W. C. Hulburt, and H. D. Brown, *Hose Pump for Applying Nitrogen Solutions*, USDA Farmer's Bulletin 2096 (1956).

35.6

37.8

40.0

42.2

44.4

48.9

53.3

57.8

62.2

66.7

88.9

80

85

90

95

100

110

120

 $130 \\ 140$

150

200

09 FERTILIZER CONVERSION FACTORS

TABLE 4.21. CONVERSION FACTORS FOR FERTILIZER MATERIALS

| Multiply | Ву | To Obtain Equivalent Nutrient |
|---|-------|---|
| Ammonia—NH ₃ | 4.700 | Ammonium nitrate—NH ₄ NO ₃ |
| $Ammonia -\!$ | 3.879 | Ammonium sulfate— $(NH_4)_2SO_4$ |
| Ammonia—NH ₃ | 0.823 | Nitrogen—N |
| Ammonium nitrate—NH ₄ NO ₃ | 0.350 | Nitrogen—N |
| Ammonium sulfate— (NH ₄) ₂ SO ₄ | 0.212 | Nitrogen—N |
| Borax—Na ₂ B ₄ O ₇ · 10H ₂ O | 0.114 | Boron—B |
| Boric acid—H ₃ BO ₃ | 0.177 | Boron—B |
| Boron—B | 8.813 | $Borax-Na_2B_4O_7 \cdot 10H_2O$ |
| Boron—B | 5.716 | Boric acid—H ₃ BO ₃ |
| Calcium—Ca | 1.399 | Calcium oxide—CaO |
| Calcium—Ca | 2.498 | Calcium carbonate—CaCO ₃ |
| Calcium—Ca | 1.849 | Calcium hydroxide—Ca(OH) ₂ |
| Calcium—Ca | 4.296 | Calcium sulfate—CaSO ₄ · 2H ₂ O (gypsum) |
| Calcium carbonate—CaCO ₃ | 0.400 | Calcium—Ca |
| Calcium carbonate—CaCO ₃ | 0.741 | Calcium hydroxide—Ca(OH) ₂ |
| Calcium carbonate—CaCO ₃ | 0.560 | Calcium oxide—CaO |
| Calcium carbonate—CaCO ₃ | 0.403 | Magnesia—MgO |
| $Calcium\ carbonateCaCO_3$ | 0.842 | ${ m Magnesium~carbonate} - { m MgCO_3}$ |
| Calcium hydroxide—Ca(OH) ₂ | 0.541 | Calcium—Ca |
| Calcium hydroxide—Ca(OH) ₂ | 1.351 | Calcium carbonate—CaCO ₃ |
| Calcium hydroxide—Ca(OH) ₂ | 0.756 | Calcium oxide—CaO |
| Calcium oxide—CaO | 0.715 | Calcium—Ca |
| Calcium oxide—CaO | 1.785 | Calcium carbonate—CaCO ₃ |
| Calcium oxide—CaO | 1.323 | Calcium hydroxide—Ca(OH) ₂ |
| Calcium oxide—CaO | 3.071 | Calcium sulfate—CaSO ₄ · 2H ₂ O (gypsum) |
| $\text{Gypsum}\text{CaSO}_4\cdot 2\text{H}_2\text{O}$ | 0.326 | Calcium oxide—CaO |
| | | |

TABLE 4.21. CONVERSION FACTORS FOR FERTILIZER MATERIALS (Continued)

| Multiply | Ву | To Obtain Equivalent Nutrient |
|---|--------|--|
| Gypsum—CaSO $_4 \cdot 2H_2O$ | 0.186 | Sulfur—S |
| Magnesia—MgO | 2.480 | Calcium carbonate—CaCO ₃ |
| Magnesia—MgO | 0.603 | Magnesium—Mg |
| Magnesia—MgO | 2.092 | Magnesium carbonate— MgCO ₃ |
| Magnesia—MgO | 2.986 | Magnesium sulfate—MgSO ₄ |
| Magnesia—MgO | 6.114 | $ \begin{array}{c} {\rm Magnesium~sulfate~MgSO_4 \cdot} \\ {\rm 7H_2O~(Epsom~salts)} \end{array} $ |
| Magnesium—Mg | 4.116 | Calcium carbonate—CaCO ₃ |
| Magnesium—Mg | 1.658 | Magnesia—MgO |
| Magnesium—Mg | 3.466 | $egin{aligned} 	ext{Magnesium carbonate} \ 	ext{MgCO}_3 \end{aligned}$ |
| Magnesium—Mg | 4.951 | $Magnesium sulfate-MgSO_4$ |
| Magnesium—Mg | 10.136 | $\begin{array}{c} {\rm Magnesium~sulfate~MgSO_4 \cdot} \\ {\rm 7H_2O~(Epsom~salts)} \end{array}$ |
| Magnesium carbonate—MgCO ₃ | 1.187 | Calcium carbonate—CaCO ₃ |
| Magnesium carbonate—MgCO ₃ | 0.478 | Magnesia—MgO |
| Magnesium carbonate—MgCO ₃ | 0.289 | Magnesium—Mg |
| $Magnesium sulfate-MgSO_4$ | 0.335 | Magnesia—MgO |
| $Magnesium sulfate-MgSO_4$ | 0.202 | Magnesium—Mg |
| Magnesium sulfate— $MgSO_4 \cdot 7H_2O$ (Epsom salts) | 0.164 | Magnesia—MgO |
| Magnesium sulfate— $MgSO_4 \cdot 7H_2O$ (Epsom salts) | 0.099 | Magnesium—Mg |
| Manganese—Mn | 2.749 | Manganese(ous) sulfate— MnSO ₄ |
| Manganese—Mn | 4.060 | Manganese(ous) sulfate— MnSO ₄ · 4H ₂ O |
| Manganese(ous) sulfate— MnSO ₄ | 0.364 | Manganese—Mn |
| $\begin{array}{c} \text{Manganese(ous) sulfate} \\ \text{MnSO}_4 \cdot 4\text{H}_2\text{O} \end{array}$ | 0.246 | Manganese—Mn |
| Nitrate—NO ₃ | 0.226 | Nitrogen—N |
| Nitrogen—N | 1.216 | Ammonia—NH ₃ |
| Nitrogen—N | 2.856 | Ammonium nitrate— NH_4NO_3 |

TABLE 4.21. CONVERSION FACTORS FOR FERTILIZER MATERIALS (Continued)

| Multiply | Ву | To Obtain Equivalent Nutrient |
|--|---------------|---|
| Nitrogen—N | 4.716 | Ammonium sulfate— |
| Nitrogen—N | 4.426 | $(\mathrm{NH_4})_2\mathrm{SO_4}$ Nitrate—NO $_3$ |
| Nitrogen—N | 6.068 | Sodium nitrate—NaNO ₃ |
| Nitrogen—N | 6.250 | Protein |
| Phosphoric acid—P ₂ O ₅ | 0.230 0.437 | Phosphorus—P |
| Phosphorus—P | 2.291 | Phosphoric acid—P ₂ O ₅ |
| Potash—K ₂ O | 1.583 | Potassium chloride—KCl |
| Potash— K_2O | 2.146 | Potassium nitrate—KNO ₃ |
| Potash— K_2O | 0.830 | Potassium—K |
| Potash— K_2O | 1.850 | Potassium sulfate—K ₂ SO ₄ |
| Potassium—K | 1.907 | Potassium chloride—KCl |
| Potassium—K | 1.205 | Potash—K ₂ O |
| Potassium—K | 2.229 | Potassium sulfate—K ₂ SO ₄ |
| Potassium chloride—KCl | 0.632 | Potash— K_2O |
| Potassium chloride—KCl | 0.524 | Potassium—K |
| Potassium nitrate—KNO ₃ | 0.466 | Potash—K ₂ O |
| Potassium nitrate—KNO ₃ | 0.400 | Potassium—K |
| Potassium sulfate—K ₂ SO ₄ | 0.540 | Potash—K ₂ O |
| Potassium sulfate— K_2SO_4 | 0.449 | Potassium—K |
| Sodium nitrate—NaNO ₃ | 0.165 | Nitrogen—N |
| Sulfur—S | 5.368 | Calcium sulfate—CaSO ₄ · |
| Sunui—S | 5.500 | 2H ₂ O (gypsum) |
| Sulfur—S | 2.497 | Sulfur trioxide—SO ₃ |
| Sulfur—S | 3.059 | Sulfuric acid—H ₂ SO ₄ |
| Sulfur trioxide—SO ₃ | 0.401 | Sulfur—S |
| Sulfuric acid—H ₂ SO ₄ | 0.327 | Sulfur—S |
| Sulfurio della 112004 | 0.021 | Sana |

<code>Examples:</code> 80 lb ammonia (NH $_3$) contains the same amount of N as 310 lb ammonium sulfate [(NH $_4$)₂SO $_4$], 80 \times 3.88 = 310. Likewise, 1000 lb calcium carbonate multiplied by 0.400 equals 400 lb calcium. A material contains 20% phosphoric acid. This percentage (20) multiplied by 0.437 equals 8.74% phosphorus.

10 NUTRIENT ABSORPTION

APPROXIMATE CROP CONTENT OF NUTRIENT ELEMENTS

Sometimes crop removal values are used to estimate fertilizer needs by crops. Removal values are obtained by analyzing plants and fruits for nutrient content and then expressing the results on an acre basis. It is risky to relate fertilizer requirements on specific soils to generalized listings of crop removal values. A major problem is that crop removal values are usually derived from analyzing plants grown on fertile soils where much of the nutrient content of the crop is supplied from soil reserves rather than from fertilizer application. Because plants can absorb larger amounts of specific nutrients than they require, crop removal values can overestimate the true crop nutrient requirement of a crop. Crop removal values can estimate the nutrient supply capacity on an unfertilized soil. The crop content (removal) values presented in the table are presented for information purposes and are not suggested for use in formulating fertilizer recommendations. The values were derived from various sources and publications. For example, a similar table was published in M. McVicker and W. Walker, Using Commercial Fertilizer (Danville, Ill.: Interstate Printers and Publishers, 1978).

TABLE 4.22. APPROXIMATE ACCUMULATION OF NUTRIENTS BY SOME VEGETABLE CROPS

| | | Nut | rient Absorp | otion |
|------------------|-------------|------------|--------------|-------|
| | Yield | | | |
| Vegetable | (cwt/acre) | N | P | K |
| Broccoli | 100 heads | 20 | 2 | 45 |
| | Other | 145 | 8 | 165 |
| | | 165 | 10 | 210 |
| Brussels sprouts | 160 sprouts | 150 | 20 | 125 |
| | Other | 85 | 9 | 110 |
| | | 235 | 29 | 235 |
| Cantaloupe | 225 fruits | 95 | 17 | 120 |
| | Vines | 60 | 8 | 35 |
| | | 155 | 25 | 155 |
| Carrot | 500 roots | 80 | 20 | 200 |
| | Tops | 65 | _5 | 145 |
| | | 145 | 25 | 345 |
| Celery | 1000 tops | 170 | 35 | 380 |
| | Roots | <u>25</u> | <u>15</u> | _55 |
| | | 195 | 50 | 435 |
| Honeydew melon | 290 fruits | 70 | 8 | 65 |
| | Vines | <u>135</u> | <u>15</u> | 95 |
| | | 205 | 23 | 160 |
| Lettuce | 350 plants | 95 | 12 | 170 |
| Onion | 400 bulbs | 110 | 20 | 110 |
| | Tops | 35 | 5 | 45 |
| | | 145 | 25 | 155 |

TABLE 4.22. APPROXIMATE ACCUMULATION OF NUTRIENTS BY SOME VEGETABLE CROPS (Continued)

| | | Nut | rient Absorp | otion |
|--------------|----------------------|-----------------------------------|---------------------------|---|
| Vegetable | Yield (cwt/acre) | N | P | K |
| Pea, shelled | 40 peas Vines | $\frac{100}{70}$ | $\frac{10}{12}$ | 30 50 80 |
| Pepper | 225 fruits Plants | $\frac{45}{95}$ | $\frac{6}{6}$ | $\frac{50}{90}$ |
| Potato | 400 tubers Vines | $\frac{150}{60}$ $\frac{210}{10}$ | $\frac{19}{11}$ | $\frac{200}{75}$ |
| Snap bean | 100 beans Plants | $\frac{120}{50}$ | $\frac{10}{\frac{6}{16}}$ | 55 45 100 |
| Spinach | 200 plants | 100 | 12 | 100 |
| Sweet corn | 130 ears Plants | 55 100 155 | $\frac{8}{12}$ 20 | $ \begin{array}{r} 30 \\ 75 \\ \hline 105 \end{array} $ |
| Sweet potato | 300 roots Vines | | $\frac{16}{\frac{4}{20}}$ | $\frac{160}{40}$ |
| Tomato | 600 fruits Vines | $\frac{100}{80}$ $\frac{80}{180}$ | 10 <u>11</u> 21 | 180 100 280 |

11 PLANT ANALYSIS

TABLE 4.23. PLANT ANALYSIS GUIDE FOR SAMPLING TIME, PLANT PART, AND NUTRIENT CONCENTRATION OF VEGETABLE CROPS (DRY WEIGHT BASIS)¹

| | | | | | Nutrie | Nutrient Level |
|-----------------------|-------------------|-----------------------|-----------------|------------------------------------|-----------|----------------|
| Crop | Time of Sampling | Plant Part | Source | $ m Nutrient$ $ m Concentration^2$ | Deficient | Sufficient |
| Asparagus | Midgrowth of fern | 4-in. tip section | NO ₃ | N, ppm | 100 | 500 |
| | | or new rern branch | FO_4 | r, ppm K, % | 800 1 | 1,600 3 |
| Bean, bush snap | ${ m Midgrowth}$ | Petiole of 4th leaf | NO ₃ | N, ppm | 2,000 | 3,000 |
| | | from tip | PO_4 | $ m P,\ ppm$ $ m K,\ \%$ | 1,000 | 2,000 5 |
| | Early bloom | Petiole of 4th leaf | NO_3 | N, ppm | 1,000 | 1,500 |
| | | from tip | PO_4 | $\frac{P}{r}$, ppm | 800 | 1,500 |
| | | | | K, % | 7 | 4 |
| Broccoli | ${ m Midgrowth}$ | Midrib of young, | ${ m NO}_3$ | N, ppm | 7,000 | 9,000 |
| | | mature leaf | PO_4 | P, ppm | 2,500 | 4,000 |
| | | | | K, % | က | 5 |
| | First buds | Midrib of young, | NO_3 | N, ppm | 5,000 | 7,000 |
| | | mature leaf | PO_4 | P, ppm | 2,500 | 4,000 |
| | | | | K, % | 2 | 4 |

| 7,000 3,500 5 | 3,000 3,000 | 7,000 3,500 | $\frac{12,000}{3,000}$ | 8,000 2,500 | 3,000 $2,000$ | 3,000 2,300 9.5 | 1,500 $1,700$ 2.5 | 800 1,500 1.8 |
|------------------------------------|---------------------------------|--|---|---|---|-----------------------------------|---|--|
| 5,000 2,000 | 2,000 $1,000$ | $\frac{2}{5,000}$ $\frac{2,500}{2}$ | 8,000 $2,000$ | $\frac{1}{5,000}$ | 2,000 $1,000$ | $\frac{2,000}{1,500}$ | 1,000 $1,300$ | $ \begin{array}{c} 1,000 \\ 1,000 \\ \end{array} $ |
| N , ppm P , ppm $K \ll \infty$ | N, ppm P, ppm P, ppm | $\mathbf{K}, \ \mathcal{N}$ $\mathbf{N}, \ \mathbf{ppm}$ $\mathbf{P}, \ \mathbf{ppm}$ $\mathbf{K} \ \mathcal{C}$ | $\sum_{\mathbf{N}} \frac{\mathbf{N}}{N}$ \mathbf{N} , ppm \mathbf{P} , ppm $\mathbf{K} \stackrel{\mathcal{S}}{\mathscr{C}}$ | $\sum_{\mathbf{N}} \sum_{\mathbf{N}} \mathbf{N}$ \mathbf{N} , ppm \mathbf{P} , ppm $\mathbf{K} \in \mathcal{C}$ | $\sum_{\mathbf{N}} \frac{\mathbf{N}}{N}$ \mathbf{N} , ppm \mathbf{P} , ppm $\mathbf{K} \stackrel{\mathcal{S}}{\mathscr{C}}$ | N, ppm P, ppm R, & | $\sum_{\mathbf{N}} \sum_{\mathbf{N}} \mathbf{N}$ \mathbf{N} , \mathbf{ppm} \mathbf{P} , \mathbf{ppm} $\mathbf{K} \in \mathcal{C}$ | I., % N, ppm P, ppm K, % |
| ${ m NO_3} \ { m PO_4}$ | ${\rm NO_3} \\ {\rm PO_4}$ | ${ m NO_3} \ { m PO_4}$ | ${\rm NO_3} \\ {\rm PO_4}$ | ${\rm NO_3} \\ {\rm PO_4}$ | ${\rm NO_3} \\ {\rm PO_4}$ | ${ m NO_3} \ { m PO_4}$ | ${\rm NO_3} \\ {\rm PO_4}$ | ${\rm NO_3} \\ {\rm PO_4}$ |
| Midrib of young, mature leaf | Midrib of young, mature leaf | Midrib of wrapper leaf | Petiole of 6th leaf from growing | Petiole of 6th leaf from growing | Petiole of 6th leaf from growing | Blade of 6th leaf from growing | Blade of 6th leaf from growing | Blade of 6th leaf from growing tip |
| Midgrowth | Late growth | At heading | Early growth (short runners) | Early fruit | First mature fruit | Early growth | Early fruit | First mature fruit |
| Brussels sprouts | | Cabbage | Cantaloupe | | | | | |

TABLE 4.23. PLANT ANALYSIS GUIDE FOR SAMPLING TIME, PLANT PART, AND NUTRIENT CONCENTRATION OF VEGETABLE CROPS (DRY-WEIGHT BASIS) (Continued)

| | | | | | Nutrier | Nutrient Level |
|-----------------------|------------------|--|----------------------------|---|-------------------------------------|---------------------|
| Crop | Time of Sampling | Plant Part | Source | $Nutrient^1$ Concentration | Deficient | Sufficient |
| Chinese cabbage | At heading | Midrib of wrapper leaf | ${\rm NO_3} \\ {\rm PO_4}$ | N, ppm P, ppm | 8,000 | 10,000 |
| Carrot | Midgrowth | Petiole of young, mature leaf | ${\rm NO_3} \\ {\rm PO_4}$ | $egin{array}{ll} K, \ \% \\ N, \ \mathrm{ppm} \\ P, \ \mathrm{ppm} \\ Y, \ \frac{M}{M} \end{array}$ | $\frac{4}{5,000}$ $2,000$ | 7,500 3,000 |
| Cauliflower | Buttoning | Midrib of young, mature leaf | ${ m NO_3} \ { m PO_4}$ | $egin{array}{ll} \mathbf{N},\ \% \ \mathbf{N},\ \mathbf{ppm} \ \mathbf{P},\ \mathbf{ppm} \ \mathbf{K},\ \% \ \mathbf{K},\ \% \end{array}$ | $\frac{4}{5,000}$ $\frac{2,500}{9}$ | 7,000 $3,500$ |
| Celery | Midgrowth | Petiole of newest fully elongated | ${\rm NO_3} \\ {\rm PO_4}$ | $\sum_{i} \frac{N_i}{N_i}$ $\sum_{i} \frac{N_i}{N_i}$ $\sum_{i} \frac{N_i}{N_i}$ $\sum_{i} \frac{N_i}{N_i}$ | 5,000 $2,500$ 4 | 7,000 $3,000$ |
| | Near maturity | Petiole of newest fully elongated leaf | ${\rm NO_3} \\ {\rm PO_4}$ | N, ppm P, ppm K, % | 4,000 2,000 3 | 6,000 3,000 5 |
| Cucumber, pickling | Early fruit set | Petiole of 6th leaf from tip | ${\rm NO_3} \\ {\rm PO_4}$ | N, ppm P, ppm K, % | 5,000 $1,500$ 3 | 7,500 2,500 5 |

TABLE 4.23. PLANT ANALYSIS GUIDE FOR SAMPLING TIME, PLANT PART, AND NUTRIENT

| 1900 | CONCENTRATION OF VEGETABLE CROPS (DRY-WEIGHT BASIS) (Continued) | VEGETABLE CROPS | S (DRY-WE | IGHT BASIS) (Co | ntinued) | |
|-----------------------|---|----------------------------------|---|---|--|---|
| | | | | | Nutrie | Nutrient Level |
| Crop | Time of Sampling | Plant Part | Source | $Nutrient^1$ Concentration | Deficient | Sufficient |
| | Early fruit set | Petiole of young, mature leaf | ${\rm NO_3} \\ {\rm PO_4}$ | N, ppm P, ppm | 1,000 $1,500$ | 1,500 |
| | Fruits, full size | Petiole of young, mature leaf | $\begin{array}{c} NO_3 \\ PO_4 \end{array}$ | K, % N, ppm P, ppm | $\begin{array}{c} 2\\ 750\\ 1,500 \end{array}$ | $\frac{4}{1,000}$ 2,000 |
| | Early growth first bloom | Blade of young, mature leaf | ${\rm NO_3} \\ {\rm PO_4}$ | K, % N , ppm P , ppm P , P | $1.5 \\ 1,500 \\ 1,500 \\ 2$ | $\begin{array}{c} 3 \\ 2,000 \\ 2,000 \\ \end{array}$ |
| | Early fruit set | Blade of young, mature leaf | ${ m NO_3} \ { m PO_4}$ | K, % N, ppm P, ppm $K %$ | $\frac{5}{500}$ $\frac{1,500}{2}$ | $\begin{array}{c} 2 \\ 800 \\ 2,000 \\ 4 \end{array}$ |
| Pepper, sweet | Early growth, first flower | Petiole of young, mature leaf | ${\rm NO_3} \\ {\rm PO_4}$ | $\sum_{i,j} \mathcal{N}_{i,j}$ N, ppm P, ppm $\sum_{i,j} p_{i,j}$ R $\mathcal{N}_{i,j}$ | 8,000 $2,000$ 4 | $\frac{10,000}{3,000}$ |
| | Early fruit set, 1 in. diameter | Petiole of young, mature leaf | ${\rm NO_3} \\ {\rm PO_4}$ | I.S. % N, ppm P, ppm K, % | 5,000 $1,500$ 3 | 7,000 2,500 5 |

| | Fruit % size | Petiole of young, mature leaf | ${ m NO}_3$ ${ m PO}_4$ | N, ppm P, ppm P , ppm $K $ | 3,000 1,200 9 | 5,000 2,000 4 |
|-----------------------------|---------------------------------|--|---|--|---------------------|----------------------------|
| | Early growth, first flower | Blade of young, mature leaf | ${\rm NO_3} \\ {\rm PO_4}$ | $ \begin{array}{c} \mathbf{N}, \ \mathcal{N} \\ \mathbf{N}, \ \mathbf{ppm} \\ \mathbf{P}, \ \mathbf{ppm} \\ \mathbf{K}, \ \mathcal{Q}, \\ \mathbf{N} \end{array} $ | 2,000 $1,800$ | $\frac{3,000}{2,500}$ |
| | Early fruit set, 1 in. diameter | Blade of young, mature leaf | ${\rm NO_3} \\ {\rm PO_4}$ | $\sum_{i} \sum_{j} N_{i}$ N, ppm P, ppm | 1,500 $1,500$ | 2,000 2,000 |
| Potato | Early season | Petiole of 4th leaf from growing | ${\rm NO_3} \\ {\rm PO_4}$ | N, ppm P, ppm R % | 8,000 1,200 9 | $\frac{4}{12,000}$ $2,000$ |
| | Midseason | Petiole of 4th leaf from growing tip | ${ m NO}_3$ ${ m PO}_4$ | N, ppm P, ppm K, % | 6,000 800 7 | 9,000 $1,600$ 9 |
| | Late season | Petiole of 4th leaf from growing tip | ${ m NO_3} \ { m PO_4}$ | N, ppm P, ppm K. % | 3,000 500 4 | 5,000 1,000 6 |
| Spinach | Midgrowth | Petiole of young, mature leaf | $\begin{array}{c} NO_3 \\ PO_4 \end{array}$ | N, ppm P, ppm K, % | 4,000 2,000 2 | 6,000 3,000 4 |
| Summer squash (zucchini) | Early bloom | Petiole of young, mature leaf | ${ m NO}_3$ ${ m PO}_4$ | N, ppm P, ppm K % | 12,000 $4,000$ | 15,000 6,000 10 |
| Sweet corn | Tasseling | Midrib of 1st leaf above primary ear | ${ m NO}_3$ ${ m PO}_4$ | N, ppm P, ppm K, % | 500 500 2 | 1,000 1,000 4 |

TABLE 4.23. PLANT ANALYSIS GUIDE FOR SAMPLING TIME, PLANT PART, AND NUTRIENT CONCENTRATION OF VEGETABLE CROPS (DRY-WEIGHT BASIS) (Continued)

| | | | | | Nutrie | Nutrient Level |
|--|-------------------------|---|---|---|---------------------|---|
| Crop | Time of Sampling | Plant Part | Source | $ m Nutrient^1$ $ m Concentration$ | Deficient | Sufficient |
| Sweet potato | Midgrowth | Petiole of 6th leaf from the | ${\rm NO_3} \\ {\rm PO_4}$ | N, ppm P, ppm | 1,500 $1,000$ | 2,500 |
| Tomato, cherry | Early fruit set | growing tip Petiole of 4th leaf from the | NO_3 PO_4 | K, % N, ppm P, ppm | 3 8,000 2,000 | $\begin{array}{c} 5 \\ 10,000 \\ 3,000 \end{array}$ |
| | Fruit ½ in. diameter | growing up Petiole of 4th leaf from growing tip | $\begin{array}{c} NO_3 \\ PO_4 \end{array}$ | K, % N, ppm P, ppm K, % | 5,000 2,000 3 | 7,000 |
| | At first harvest | Petiole of 4th leaf from growing tip | PO_3 | $egin{array}{ll} N, & \mathrm{ppm} \\ P, & \mathrm{ppm} \\ K, & \% \end{array}$ | 1,000 $2,000$ 2 | 2,000 3,000 4 |
| Tomato, processing and determinate, fresh market | Early bloom | Petiole of 4th leaf from growing tip | ${ m NO_3} \ { m PO_4}$ | N, ppm P, ppm K, % | 8,000 2,000 3 | 12,000 3,000 6 |

| | Fruit 1 in. | Petiole of 4th leaf | NO_3 | N, ppm | 4,000 | 000,9 |
|---------------|-----------------|---------------------|-----------------|--------|--------|--------|
| | diameter | from growing | PO_4 | P, ppm | 1,500 | 2,500 |
| | | tip | | K, % | 2 | 4 |
| | First color | Petiole of 4th leaf | NO_3 | N, ppm | 2,000 | 3,000 |
| | | from growing | PO_4 | P, ppm | 1,000 | 2,000 |
| | | tip | | K, % | 1 | က |
| Tomato, fresh | Early bloom | Petiole of 4th leaf | NO_3 | N, ppm | 10,000 | 14,000 |
| market | | from growing | PO_4 | P, ppm | 2,500 | 3,000 |
| indeterminate | | tip | | K, % | 4 | 7 |
| | Fruit 1 in. | Petiole of 4th leaf | NO_3 | N, ppm | 8,000 | 12,000 |
| | diameter | from growing | PO_4 | P, ppm | 2,500 | 3,000 |
| | | tip | | K, % | က | 5 |
| | Full ripe fruit | Petiole of 4th leaf | NO_3 | N, ppm | 4,000 | 000,9 |
| | | from growing | PO_4 | P, ppm | 2,000 | 2,500 |
| | | tip | | K, % | 2 | 4 |
| Watermelon | Early fruit set | Petiole of 6th leaf | NO_3 | N, ppm | 5,000 | 7,500 |
| | | from growing | PO_4 | P, ppm | 1,500 | 2,500 |
| | | tip | | K, % | က | 5 |

California, Davis. O.A. Lorenz and K.B. Tyler, Plant Tissue Analysis of Vegetable Crops (University of California—Davis Vegetable Research and Information Center), http://vric.ucdavis.edu/veginfo/topics/fertilizer/tissueanalysis.pdf. Values represent conventionally fertilized crops. Organically managed crops may Adapted from H. M. Reisenauer (ed.), Soil and Plant Tissue Testing in California, University of California Division of Agricultural Science Bulletin 1879 ²Two percent acetic acid-soluble NO₃-N and PO₄-P and total K (dry weight basis). Updated 1995, personal communication, T. K. Hartz, University of

show lower petiole-nitrate (NO₃-N) concentrations. Total macronutrient concentrations of whole leaves is the preferred method of evaluating nutrient

sufficiency under organic fertility management.

TABLE 4.24. TOTAL NUTRIENT CONCENTRATION FOR DIAGNOSIS OF THE NUTRIENT LEVEL OF VEGETABLE CROPS

| | | | | Nutrier (% dry | Nutrient Level (% dry weight) |
|-----------------|-------------------|----------------------|----------|-------------------|----------------------------------|
| Crop | Time of Sampling | Plant Part | Nutrient | Deficient | Sufficient |
| Asparagus | Early fern growth | 4-in. tip section of | Z | 4.00 | 5.00 |
| | | new fern branch | J X | 0.20 | 0.40 4.00 |
| | Mature fern | 4-in. tip section of | Z | 3.00 | 4.00 |
| | | new fern branch | Ь | 0.20 | 0.40 |
| | | | K | 1.00 | 3.00 |
| Bean, bush snap | Full bloom | Petiole: recent | Z | 1.50 | 2.25 |
| | | fully exposed | Ь | 0.15 | 0.30 |
| | | trifoliate leaf | K | 1.00 | 2.50 |
| | Full bloom | Blade: recent fully | Z | 1.25 | 2.25 |
| | | exposed | Ь | 0.25 | 0.40 |
| | | trifoliate leaf | K | 0.75 | 1.50 |
| Bean, lima | Full bloom | Oldest trifoliate | Z | 2.50 | 3.50 |
| | | leaf | Ь | 0.20 | 0.30 |
| | | | K | 1.50 | 2.25 |
| Celery | Midgrowth | Petiole | Z | 1.00 | 1.50 |
| | | | Ь | 0.25 | 0.55 |
| | | | K | 4.00 | 5.00 |

| Cantaloupe | Early growth | Petiole of 6th leaf | Z | 2.50 | 3.50 |
|------------|---------------------|---------------------|---|------|------|
| | | from growing tip | Ь | 0.30 | 0.60 |
| | | | K | 4.00 | 00.9 |
| | Early fruit | Petiole of 6th leaf | Z | 2.00 | 3.00 |
| | | from growing tip | Ь | 0.20 | 0.35 |
| | | | K | 3.00 | 5.00 |
| | First mature fruit | Petiole of 6th leaf | Z | 1.50 | 2.00 |
| | | from growing tip | Ь | 0.15 | 0.30 |
| | | | K | 2.00 | 4.00 |
| Garlic | Early season | Newest fully | Z | 4.00 | 5.00 |
| | (prebulbing) | elongated leaf | Ь | 0.20 | 0.30 |
| | | | K | 3.00 | 4.00 |
| | Midseason (bulbing) | Newest fully | Z | 3.00 | 4.00 |
| | | elongated leaf | Ь | 0.20 | 0.30 |
| | | | K | 2.00 | 3.00 |
| | Late season | Newest fully | Z | 2.00 | 3.00 |
| | (postbulbing) | elongated leaf | Ь | 0.20 | 0.30 |
| | | | K | 1.00 | 2.00 |
| Lettuce | At heading | Leaves | Z | 1.50 | 3.00 |
| | | | Ь | 0.20 | 0.35 |
| | | | K | 2.50 | 5.00 |
| | Nearly mature | Leaves | Z | 1.25 | 2.50 |
| | | | Ь | 0.15 | 0.30 |
| | | | K | 2.50 | 5.00 |
| Onion | Early season | Tallest leaf | Z | 3.00 | 4.00 |
| | | | Ь | 0.10 | 0.20 |
| | | | K | 3.00 | 4.00 |
| | | | | | |

TABLE 4.24. TOTAL NUTRIENT CONCENTRATION FOR DIAGNOSIS OF THE NUTRIENT LEVEL OF VEGETABLE CROPS (Continued)

| | | | | Nutrier (% dry | Nutrient Level (% dry weight) |
|---------------|----------------------|---------------------|----------|-------------------|----------------------------------|
| Crop | Time of Sampling | Plant Part | Nutrient | Deficient | Sufficient |
| | Midseason | Tallest leaf | Z | 2.50 | 3.00 |
| | | | Ъ | 0.10 | 0.20 |
| | | | K | 2.50 | 4.00 |
| | Late season | Tallest leaf | Z | 2.00 | 2.50 |
| | | | Ъ | 0.10 | 0.20 |
| | | | K | 2.00 | 3.00 |
| Pepper, sweet | Full bloom | Blade and petiole | Z | 3.00 | 4.00 |
| | | | Ъ | 0.15 | 0.25 |
| | | | K | 1.50 | 2.50 |
| | Full bloom, fruit % | Blade and petiole | Z | 2.50 | 3.50 |
| | size | | Ъ | 0.12 | 0.20 |
| | | | K | 1.00 | 2.00 |
| Potato | Early, plants 12 in. | Petiole of 4th leaf | Z | 2.50 | 3.50 |
| | tall | from tip | Ъ | 0.20 | 0.30 |
| | | | K | 9.00 | 11.00 |
| | Midseason | Petiole of 4th leaf | Z | 2.25 | 2.75 |
| | | from tip | Ъ | 0.10 | 0.20 |
| | | | K | 7.00 | 9.00 |

| h leaf | | Late, nearly mature | Petiole of 4th leaf | Z | 1.50 | 2.25 |
|--|-----------|---|---------------------|---|------|------|
| Early, plants 12 in. Blade of 4th leaf from tip K 4.00 tall from tip K 3.50 Midseason Blade of 4th leaf N 3.00 from tip K 2.50 Late, nearly mature Blade of 4th leaf N 2.00 from tip K 2.00 R 1.50 1.00 Midgrowth Mature leaf blade N 2.00 At harvest Mature leaf blade N 1.50 At harvest Mature leaf blade N 1.50 At barvest Mature leaf blade N 2.00 At barvest Mature leaf blade N 0.20 Base of plant K 1.75 Bart P 0.20 <tr< td=""><td></td><td></td><td>from tip</td><td>Ъ</td><td>80.0</td><td>0.15</td></tr<> | | | from tip | Ъ | 80.0 | 0.15 |
| Early, plants 12 in. Blade of 4th leaf from tip N 4.00 tall from tip K 3.50 Midseason Blade of 4th leaf N 3.00 from tip K 2.50 ea Full bloom Blade and petiole N 2.00 Midgrowth Mature leaf blade N 2.00 At harvest Mature leaf blade N 2.00 At harvest Mature leaf blade N 2.00 At harvest Mature leaf blade N 2.00 At barvest Mature leaf blade N 2.00 K 1.50 0.20 At barvest Mature leaf blade N 2.00 K 1.50 0.20 At barvest Mature leaf blade N 2.00 At barvest Mature leaf blade N 2.00 At barvest Mature leaf blade N 2.00 Base of plant K 1.75 Bar 0.20 0.20 <td></td> <td></td> <td></td> <td>K</td> <td>4.00</td> <td>00.9</td> | | | | K | 4.00 | 00.9 |
| tall from tip P 0.30 Midseason Blade of 4th leaf N 3.50 Late, nearly mature Blade of 4th leaf N 2.00 from tip K 1.50 ea Full bloom Blade and petiole N 2.00 Midgrowth Mature leaf blade N 2.00 At harvest Mature leaf blade N 1.50 and petiole K 2.00 K 2.00 2.00 At harvest Mature leaf blade N 1.50 and petiole K 2.00 K 2.00 2.00 Sixth leaf from N 2.75 base of plant K 1.75 car F 1.00 K 1.00 K 1.75 ear K 1.75 Carlo 2.00 K 1.00 K 1.00 K 1.75 Carlo | | Early, plants 12 in. | Blade of 4th leaf | Z | 4.00 | 00.9 |
| Kidseason Blade of 4th leaf from tip K 3.50 from tip P 0.20 K 2.50 from tip K 2.50 from tip K 1.50 from tip K 1.50 K 1.00 K Midgrowth Mature leaf blade N 2.00 At harvest Mature leaf blade N 1.50 and petiole K 3.00 K 2.00 K 2.00 Sixth leaf from K 2.75 base of plant K 1.75 Silking Leaf opposite first N 1.50 ear K 1.00 | | tall | from tip | Ъ | 0.30 | 09.0 |
| Midseason Blade of 4th leaf from tip N 3.00 from tip K 2.50 Late, nearly mature Blade of 4th leaf N 2.00 from tip K 1.50 R 1.50 P 0.10 R 1.50 P 0.20 K 1.00 Mature leaf blade N 2.00 At harvest Mature leaf blade N 1.50 and petiole K 3.00 K 2.00 Sixth leaf from N 2.75 base of plant K 1.75 Silking Leaf opposite first N 1.75 F 1.00 0.20 | | | 1 | Ж | 3.50 | 5.00 |
| from tip P 0.20 Late, nearly mature Blade of 4th leaf N 2.50 from tip K 1.50 Rull bloom Blade and petiole N 2.00 Midgrowth Mature leaf blade N 2.00 At harvest Mature leaf blade N 2.00 At harvest Mature leaf blade N 1.50 At barvest Mature leaf blade N 2.00 R Abase of plant P 0.20 R 1.75 2.00 Base of plant R 1.75 Base of plant R 1.75 Base of plant R 1.75 Car P 0.20 Car P 0.20 F 1.00 | | Midseason | Blade of 4th leaf | Z | 3.00 | 5.00 |
| Late, nearly mature Blade of 4th leaf N 2.00 from tip K 1.50 K 1.50 K 1.50 R 1.60 Midgrowth Mature leaf blade N 2.00 At harvest Mature leaf blade N 2.00 At harvest Mature leaf blade N 1.50 and petiole K 3.00 At base of plant K 2.00 K 2.00 K 3.00 K 3.0 | | | from tip | Ъ | 0.20 | 0.40 |
| Late, nearly mature from tip from from from from from from from from | | | 1 | Ж | 2.50 | 3.50 |
| from tip F 0.10 K 1.50 Blade and petiole N 2.00 K 1.00 Midgrowth Mature leaf blade N 2.00 At harvest Mature leaf blade N 1.50 and petiole K 3.00 Tasseling Sixth leaf from N 2.75 base of plant F 0.18 K 1.75 ear F 0.20 ear F 1.75 F 1.00 | | Late, nearly mature | Blade of 4th leaf | Z | 2.00 | 4.00 |
| ea Full bloom Blade and petiole N 2.00 P 0.20 K 1.00 Midgrowth Mature leaf blade N 2.00 At harvest Mature leaf blade N 1.50 and petiole K 3.00 Tasseling Sixth leaf from N 2.75 base of plant P 0.18 K 1.75 ear F 0.20 ear K 1.50 K 1.00 | | | from tip | Ь | 0.10 | 0.20 |
| ea Full bloom Blade and petiole N 2.00 Midgrowth Mature leaf blade N 2.00 At harvest Mature leaf blade N 2.00 At harvest Mature leaf blade N 1.50 and petiole K 2.00 Tasseling Sixth leaf from N 2.75 base of plant P 0.18 k 1.75 car East opposite first N 1.50 ear K 1.50 | | | | K | 1.50 | 2.50 |
| Midgrowth Mature leaf blade N 0.20 At harvest Mature leaf blade K 3.00 At harvest Mature leaf blade N 1.50 and petiole F 0.20 K 2.00 Sixth leaf from N 2.75 base of plant F 0.18 Leaf opposite first N 1.75 ear F 0.20 K 1.00 | thern pea | Full bloom | Blade and petiole | Z | 2.00 | 3.50 |
| Midgrowth Mature leaf blade N 2.00 and petiole F 0.20 K 3.00 At harvest Mature leaf blade N 1.50 and petiole F 0.20 K 2.00 Sixth leaf from N 2.75 base of plant F 0.18 K 1.75 ear F 0.20 ear F 1.50 K 1.00 | cowpea) | | | Ь | 0.20 | 0.30 |
| Midgrowth Mature leaf blade N 2.00 At harvest Mature leaf blade N 1.50 At harvest and petiole P 0.20 Tasseling Sixth leaf from N 2.75 base of plant P 0.18 K 1.75 Silking Leaf opposite first N 1.50 ear K 1.50 K 1.00 | | | | K | 1.00 | 2.00 |
| and petiole P 0.20 K 3.00 At harvest Mature leaf blade N 1.50 and petiole F 0.20 K 2.00 Sixth leaf from N 2.75 base of plant F 0.18 K 1.75 Silking Leaf opposite first N 1.50 ear K 1.00 | nach | $egin{align} 	ext{Midgrowth} \end{aligned}$ | Mature leaf blade | Z | 2.00 | 4.00 |
| At harvest Mature leaf blade N 1.50 and petiole P 0.20 K 2.00 Sixth leaf from N 2.75 base of plant P 0.18 K 1.75 Silking Leaf opposite first N 1.50 ear K 1.00 | | | and petiole | Ь | 0.20 | 0.40 |
| At harvest Mature leaf blade N 1.50 and petiole F 0.20 K 2.00 Sixth leaf from N 2.75 base of plant F 0.18 K 1.75 Silking Leaf opposite first N 1.50 ear K 1.00 | | | | K | 3.00 | 00.9 |
| and petiole P 0.20 K 2.00 Sixth leaf from N 2.75 base of plant P 0.18 K 1.75 Silking Leaf opposite first N 1.50 ear K 1.00 | | At harvest | Mature leaf blade | Z | 1.50 | 3.00 |
| Tasseling Sixth leaf from N N 2.00 base of plant P 0.18 K 1.75 Silking Leaf opposite first N 1.50 ear K 1.00 | | | and petiole | Ь | 0.20 | 0.35 |
| Tasseling Sixth leaf from base of plant N 2.75 base of plant P 0.18 K 1.75 Silking Leaf opposite first N 1.50 ear F 0.20 K 1.00 | | | | K | 2.00 | 5.00 |
| base of plant P 0.18 K 1.75 Silking Leaf opposite first N 1.50 ear P 0.20 K 1.00 | eet corn | Tasseling | Sixth leaf from | Z | 2.75 | 3.50 |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | base of plant | Ь | 0.18 | 0.28 |
| Leaf opposite first N 1.50 ear P 0.20 K 1.00 | | | | K | 1.75 | 2.25 |
| P 0.20 K 1.00 | | Silking | Leaf opposite first | Z | 1.50 | 2.00 |
| | | | ear | Ь | 0.20 | 0.30 |
| | | | | X | 1.00 | 2.00 |

TABLE 4.24. TOTAL NUTRIENT CONCENTRATION FOR DIAGNOSIS OF THE NUTRIENT LEVEL OF VEGETABLE CROPS (Continued)

| t Level weight) | Sufficient | 3.50 0.30 2.50 2.50 2.00 |
|----------------------------------|-----------------------|--|
| Nutrient Level (% dry weight) | Deficient | 2.50 0.20 1.50 1.50 0.15 1.00 |
| | Nutrient | $Z \land Z \land Z \land M$ |
| | Plant Part | Leaf blade and petiole Leaf blade and petiole |
| | Time of Sampling | Flowering First ripe fruit |
| | Crop | Tomato (determinate) |

Adapted from H. M. Reisenauer (ed.), Soil and Plant Tissue Testing in California, University of California Division of Agricultural Science Bulletin 1879 (1983). Updated 1995, personal communication, T. K. Hartz, University of California—Davis.

CRITICAL (DEFICIENCY) VALUES, ADEQUATE RANGES, HIGH VALUES, AND TOXICITY VALUES FOR PLANT NUTRIENT CONCENTRATION OF VEGETABLES **TABLE 4.25.**

| | | | | | | % | | | | | | mdd | и | | |
|-------------|---------------------------------|---------------------|---------------|-------------|----------------|-------|-----|------|----------|-----|------|-----|-----|------------------|------|
| Crop | Plant Part ¹ | Time of Sampling | Status | z | д | × | Ca | Mg | ∞ | Fe | Mn | Zn | В | $C_{\mathbf{n}}$ | Mo |
| Bean, snap | MRM | Before bloom | Deficient | <3.0 | 0.25 | 2.0 | 8.0 | 0.20 | 0.20 | 25 | 20 | 20 | 15 | 20 | - 1 |
| | $\operatorname{trifoliate}_{i}$ | | Adequate | 3.0 | 0.25 | 2.0 | 8.0 | 0.20 | 0.40 | 25 | 20 | 20 | 15 | ر د م | 0.4 |
| | leaf | | range High | 4.0 74.1 | $0.45 \\ 0.46$ | 0. 6. | 1.5 | 0.45 | 0.40 | 200 | 100 | 40 | 40 | 9 9 | i. |
| | | | Toxic (>) | | | | | | | | 1000 | | 150 | | |
| | MRM | First bloom | Deficient | <3.0 | 0.25 | 2.0 | 8.0 | 0.25 | 0.20 | 25 | 20 | 20 | 15 | 50 | |
| | trifoliate | | Adequate | 3.0 | 0.25 | 2.0 | 8.0 | 0.26 | 0.21 | 25 | 20 | 20 | 15 | ro | 0.4 |
| | leaf | | range | 4.0 | 0.45 | 3.0 | 1.5 | 0.45 | 0.40 | 200 | 100 | 40 | 40 | 10 | 1.0 |
| | | | High | >4.1 | 0.46 | 3.1 | 1.6 | 0.45 | 0.40 | 200 | 100 | 40 | 40 | 10 | |
| | | | Toxic (>) | 1 | I | | 1 | | I | I | 1000 | | 150 | | |
| | MRM | Full bloom | Deficient | <2.5 | 0.20 | 1.5 | 8.0 | 0.25 | 0.20 | 25 | 20 | 20 | 15 | ro | |
| | trifoliate | | Adequate | 2.5 | 0.20 | 1.6 | 8.0 | 0.26 | 0.21 | 25 | 20 | 20 | 15 | ro | 0.4 |
| | | | range | 4.0 | 0.40 | 2.5 | 1.5 | 0.45 | 0.40 | 200 | 100 | 40 | 40 | 10 | 1.0 |
| | | | High | >4.1 | 0.41 | 2.5 | 1.6 | 0.45 | 0.40 | 200 | 100 | 40 | 40 | 10 | |
| | | | Toxic (>) | | I | I | I | I | I | I | 1000 | I | 150 | 1 | |
| Beet, table | Leaf blades | 5 weeks | Deficient | <3.0 | 0.22 | 2.0 | 1.5 | 0.25 | I | 40 | 30 | 15 | 30 | J. | 0.05 |
| | | after seeding | Adequate | 3.0 | 0.25 | 2.0 | 1.5 | 0.25 | 0.60 | 40 | 30 | 15 | 30 | ro | 0.20 |
| | | | range | 5.0 | 0.40 | 0.9 | 2.0 | 1.00 | 0.80 | 200 | 200 | 30 | 80 | 10 | 0.60 |
| | | | High | >5.0 | 0.40 | 0.9 | 2.0 | 1.00 | | | | | 80 | 10 | |

0.3 0.6 0.6 0.04 0.160.16Mo09.0 0.04 0.04 CRITICAL (DEFICIENCY) VALUES, ADEQUATE RANGES, HIGH VALUES, AND TOXICITY Z, 10 10 10 920 001 VALUES FOR PLANT NUTRIENT CONCENTRATION OF VEGETABLES (Continued) М mdd 00 Z_{n} 150 150 200 200 20 40 Mn150 300 300 150 30 Fe 50 0.2008.0 0.200.200.80 08.0 0.30S 0.400.300.230.40 0.20 0.200.40).25).2500. 90. 0.230.40 Mg9.8 2.5 9.4 0.4 Ça 8 X 0.20 0.20 0.300.300.30 0.300.50 0.500.20 0.20 0.60 0.60 0.30 0.30 Д <2.5 <3.0 >4.5 <2.2 <3.2 3.0 4.52.25.0>5.0 >4.0 Z Adequate Adequate Adequate Adequate Status Toxic (>) Deficient Toxic (>) Deficient Deficient Deficient range range range High High High after seeding Sampling Time of sprouts Heading 9 weeks At early 5 weeks after Plant Part¹ blades leaf leaf leaf MRMMRMMRMLeaf **TABLE 4.25.** Cropsprouts Brussels Cabbage Broccoli

10

00

9

0.60 0.60

range

transplanting

| | MRM | 8 weeks | Deficient | <3.0 | 0.30 | 2.0 | 0.5 | 0.20 | I | 30 | 20 | 30 | 20 | အ | 0.3 |
|---------|---------|----------------|-----------|---------------|------|-----|-----|------|------|-----|-----|----|-----|--------------|-----|
| | leaf | after | Adequate | 3.0 | 0.30 | 2.0 | 1.5 | 0.25 | 0.30 | 30 | 20 | 30 | 20 | က | 0.3 |
| | | transplanting | range | 6.0 | 0.60 | 4.0 | 2.0 | 09.0 | I | 09 | 40 | 20 | 40 | 7 | 9.0 |
| | | | High | >6.0 | 0.60 | 4.0 | 2.0 | 09.0 | | 100 | 40 | 20 | 40 | 10 | ı |
| | Wrapper | Heads | Deficient | <3.0 | 0.30 | 1.7 | 0.5 | 0.25 | I | 20 | 20 | 20 | 30 | 4 | 0.3 |
| | leaf | $^{1/2}$ grown | Adequate | 3.0 | 0.30 | 2.3 | 1.5 | 0.25 | 0.30 | 20 | 20 | 20 | 30 | 4 | 0.3 |
| | | | range | 4.0 | 0.50 | 4.0 | 2.0 | 0.45 | | 40 | 40 | 30 | 20 | œ | 9.0 |
| | | | High | >4.0 | 0.50 | 4.0 | 2.0 | 0.45 | I | 100 | 40 | 40 | 20 | 10 | 1 |
| | Wrapper | At harvest | Deficient | \ \ 1.8 | 0.26 | 1.2 | 0.5 | 0.25 | I | 20 | 20 | 20 | 30 | 4 | 0.3 |
| | leaf | | Adequate | 1.8 | 0.26 | 1.5 | 1.5 | 0.25 | 0.30 | 20 | 20 | 20 | 30 | 4 | 0.3 |
| | | | range | 3.0 | 0.40 | 3.0 | 2.0 | 0.45 | I | 40 | 40 | 30 | 20 | _∞ | 9.0 |
| | | | High | >3.0 | 0.40 | 3.0 | 2.0 | 0.45 | I | 100 | 40 | 40 | 20 | 10 | 1 |
| taloupe | MRM | 12-in. | Deficient | <4.0 | 0.40 | 5.0 | 3.0 | 0.35 | | 40 | 20 | 20 | 20 | 5 | 9.0 |
| | leaf | vines | Adequate | 4.0 | 0.40 | 5.0 | 3.0 | 0.35 | 0.20 | 40 | 20 | 20 | 20 | 5 | 9.0 |
| | | | range | 5.0 | 0.70 | 7.0 | 5.0 | 0.45 | 0.50 | 100 | 100 | 09 | 80 | 10 | 1.0 |
| | | | High | >5.0 | 0.70 | 7.0 | 5.0 | 0.45 | I | 100 | 100 | 09 | 80 | 10 | 1.0 |
| | | | Toxic (>) | | I | I | 1 | I | | 1 | 006 | 1 | 150 | ı | ı |
| | MRM | Early fruit | Deficient | <3.5 | 0.25 | 1.8 | 1.8 | 0.30 | 1 | 40 | 20 | 20 | 20 | 5 | 9.0 |
| | leaf | set | Adequate | 3.5 | 0.25 | 1.8 | 1.8 | 0.30 | 0.20 | 40 | 20 | 20 | 20 | 5 | 9.0 |
| | | | range | 4.5 | 0.40 | 4.0 | 5.0 | 0.40 | 0.50 | 100 | 100 | 09 | 80 | 10 | 1.0 |
| | | | High | >4.5 | 0.40 | 4.0 | 5.0 | 0.40 | I | 100 | 100 | 09 | 80 | 10 | 1.0 |
| | | | Toxic (>) | I | | | | | I | I | 006 | 1 | 150 | ı | ı |
| rot | MRM | 60 days | Deficient | ×1.8 | 0.20 | 2.0 | 1.0 | 0.15 | | 30 | 30 | 20 | 20 | 4 | ı |
| | leaf | after seeding | Adequate | 1.8 | 0.20 | 2.0 | 2.0 | 0.20 | I | 30 | 30 | 20 | 20 | 4 | 1 |
| | | | range | 2.5 | 0.40 | 4.0 | 3.5 | 0.50 | | 09 | 09 | 09 | 40 | 10 | l |
| | | | High | >2.5 | 0.40 | 4.0 | 3.5 | 0.50 | | 09 | 100 | 09 | 40 | 10 | ı |
| | MRM | Harvest | Deficient | $^{<}1.5$ | 0.18 | 1.0 | 1.0 | 0.25 | I | 20 | 30 | 20 | 20 | 4 | ı |

TABLE 4.25. CRITICAL (DEFICIENCY) VALUES, ADEQUATE RANGES, HIGH VALUES, AND TOXICITY VALUES FOR PLANT NUTRIENT CONCENTRATION OF VEGETABLES (Continued)

| | Mo | | | 1 | I | | I | | I | I | | 1 | I | | | I | | 1 | | | I |
|-----|-----------------------|---|----------|-------|------|-------------|----------|-------|---------|-----------|----------|-------|------|-----------|----------|---------------|------|-------------|----------|-------|------|
| | Cu | | 4 | 10 | 10 | က | ro | 10 | 10 | ro | က | 10 | 10 | 4 | 4 | 9 | I | Н | Н | က | က |
| _ | В | , | 20 | 40 | 40 | 30 | 30 | 20 | 20 | 30 | 30 | 20 | 50 | 15 | 15 | 25 | 25 | 20 | 20 | 40 | 40 |
| udd | Zn | | 20 | 09 | 09 | 30 | 30 | 20 | 20 | 30 | 30 | 20 | 20 | 20 | 20 | 40 | 09 | 20 | 20 | 40 | 09 |
| | Mn | | 30 | 09 | 100 | 30 | 30 | 80 | 100 | 20 | 20 | 80 | 100 | 73 | 73 | 10 | 20 | 70 | 5 | 10 | 20 |
| | Fe | | 20 | 30 | 09 | 30 | 30 | 09 | 100 | 30 | 30 | 09 | 100 | 20 | 20 | 30 | 100 | 20 | 20 | 30 | 100 |
| | ∞ | | | I | | 0.60 | 0.60 | 1.00 | I | I | I | | I | | I | I | I | | | | |
| | Mg | : | 0.40 | 0.50 | 0.50 | 0.25 | 0.25 | 0.60 | 0.60 | 0.25 | 0.25 | 0.60 | 09.0 | 0.30 | 0.30 | 09.0 | 0.60 | 0.30 | 0.30 | 0.60 | 09.0 |
| ,0 | Ca | | 1.0 | 1.5 | 1.5 | 8.0 | 8.0 | 2.0 | 2.0 | 1.0 | 1.0 | 2.0 | 2.0 | 1.3 | 1.3 | 2.0 | 2.0 | 1.3 | 1.3 | 2.0 | 2.0 |
| % | K | | 1.4 | 4.0 | 4.0 | 2.0 | 2.0 | 4.0 | 4.0 | 1.5 | 1.5 | 3.0 | 3.0 | 6.0 | 6.0 | 8.0 | 8.0 | 5.0 | 5.0 | 7.0 | 7.0 |
| | Ъ | | 0.18 | 0.40 | 0.40 | 0.40 | 0.40 | 0.70 | 0.70 | 0.30 | 0.30 | 0.70 | 0.70 | 0.30 | 0.30 | 0.60 | 0.60 | 0.30 | 0.30 | 0.60 | 09.0 |
| | Z | , | 1.5 | 2.5 | >2.5 | <3.0 | 3.0 | 5.0 | > 5.0 | <2.2 | 2.2 | 4.0 | >4.0 | <1.5 | 1.5 | 1.7 | >1.7 | <1.5 | 1.5 | 1.7 | >1.7 |
| | Status | | Adequate | range | High | Deficient | Adequate | range | High | Deficient | Adequate | range | High | Deficient | Adequate | range | High | Deficient | Adequate | range | High |
| | Time of Sampling | | | | | Buttoning | | | | Heading | | | | 6 weeks | after | transplanting | | At maturity | | | |
| | ${\rm Plant~Part}^1$ | | leaf | | | MRM | leaf | | | MRM | leaf | | | Outer | petiole | | | Outer | petiole | | |
| | Crop | | | | | Cauliflower | | | | | | | | Celery | | | | | | | |

| 1 | I | 1 | 1 | 1 | 1 | I | I | 1 | I | I | 1 | I | I | 1 | I | 0.2 | 0.3 | 1.0 | 2.0 | 0.2 | 0.3 | 1.0 | 2.0 | I | 0.5 | 0.5 | 8.0 |
|-------------|-----------|-----------|------|-------------|-----------|-------|------|--------------|----------|-------|------|-------------|----------|------|------|--------------|----------|-------|------|-------------|----------|-------|------|-----------|-------------|----------|-------|
| 20 | 2 | 10 | 10 | 4 | 4 | 9 | 9 | ည | 5 | 10 | 10 | 5 | 2 | 10 | 10 | က | ည | 20 | 20 | 2 | 5 | 20 | 20 | | က | ည | 10 |
| 15 | 15 | 25 | 25 | 30 | 30 | 20 | 20 | 25 | 25 | 20 | 20 | 25 | 25 | 20 | 20 | 20 | 20 | 09 | 09 | 20 | 20 | 09 | 09 | 150 | 20 | 20 | 40 |
| 30 | 30 | 20 | 20 | 20 | 20 | 40 | 40 | 25 | 25 | 20 | 20 | 20 | 20 | 40 | 40 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 950 | 20 | 20 | 40 |
| ∞ | 14 | 20 | 20 | 7 | 13 | 19 | 20 | 40 | 40 | 100 | 100 | 40 | 40 | 100 | 100 | 30 | 30 | 100 | 100 | 30 | 30 | 100 | 100 | 006 | 20 | 20 | 100 |
| 1 | I | I | | I | I | | I | 40 | 40 | 100 | 100 | 40 | 40 | 100 | 100 | 40 | 40 | 100 | 100 | 40 | 40 | 100 | 100 | | 20 | 20 | 100 |
| | 1 | 1 | | | 1 | | 1 | 1 | | 1 | 1 | | 1 | 1 | | 0.30 | 0.30 | 0.80 | 0.80 | 0.30 | 0.30 | 0.80 | 0.80 | | 0.40 | 0.40 | 09.0 |
| 0.35 | 0.35 | 0.45 | 0.45 | 0.40 | 0.40 | 0.50 | 0.50 | 0.40 | 0.40 | 1.00 | 1.00 | 0.35 | 0.35 | 0.10 | 0.10 | 9.58 | 9.58 | 0.70 | 0.70 | 0.30 | 0.30 | 09.0 | 09.0 | | 0.25 | 0.25 | 09.0 |
| 4.5 | 4.5 | 5.0 | 5.0 | 1 | 3.7 | 0.9 | 0.9 | 1.0 | 1.0 | 2.0 | 2.0 | 1.0 | 1.0 | 2.0 | 2.0 | 2.0 | 2.0 | 4.0 | 4.0 | 1.3 | 1.3 | 3.5 | 3.5 | I | 8.0 | 8.0 | 1.5 |
| 7.5 | 7.5 | 8.5 | 8.5 | 3.0 | 3.0 | 6.5 | 6.5 | 3.0 | 3.0 | 5.0 | 5.0 | 2.5 | 2.5 | 4.0 | 4.0 | 1.6 | 1.6 | 3.0 | 3.0 | 1.6 | 1.6 | 3.0 | 3.0 | | 3.5 | 3.5 | 5.0 |
| 0.50 | 0.50 | 09.0 | 09.0 | 0.30 | 0.30 | 09.0 | 09.0 | 0.30 | 0.30 | 09.0 | 09.0 | 0.25 | 0.25 | 0.50 | 0.50 | 0.30 | 0.30 | 09.0 | 09.0 | 0.25 | 0.25 | 09.0 | 09.0 | | 0.30 | 08.0 | 09.0 |
| <4.5 | 4.5 | | >5.0 | _ | | 4.0 | | | | | | | | | | | | 0.9 | | | | | >5.0 | | <4.2 (| 4.2 | 5.0 |
| Deficient < | Adequate | range | High | ٧ | Adequate | range | | Deficient < | Adequate | range | | Deficient < | Adequate | | High | | Adequate | range | High | | Adequate | range | High | Toxic (>) | ٧ | Adequate | range |
| 8-leaf | stage | | | At maturity | | | | Young plants | | | | Harvest | | | | Before bloom | | | | Early bloom | | | | | Early fruit | set | |
| Oldest | undamaged | leaf | | Oldest | undamaged | leaf | | Tops | | | | MRM | leaf | | | MRM | leaf | | | MRM | leaf | | | | MRM | leaf | |
| Chinese | cabbage | (heading) | | | | | | Collards | | | | | | | | Cucumber | | | | | | | | | Eggplant | | |

TABLE 4.25. CRITICAL (DEFICIENCY) VALUES, ADEQUATE RANGES, HIGH VALUES, AND TOXICITY VALUES FOR PLANT NUTRIENT CONCENTRATION OF VEGETABLES (Continued)

| | | | | | | % | . 0 | | | | | mdd | а | | |
|----------|-----------------------|---------------------|-----------|-------------|------|-----|---------|------|-----|-----|-----|-----|----|------|-----|
| Crop | $\rm Plant\ Part^{1}$ | Time of Sampling | Status | z | д | M | Ca | Mg | ω | Fe | Mn | Zn | В | Cu | Mo |
| | | | Hioh | 0 9 < | 090 | 7.0 | , rc | 090 | 090 | 100 | 100 | 40 | 40 | 10 | σ |
| Endive | Oldest | 8-leaf | Deficient | <4.5 4.5 | 0.45 | 4.5 | 2.0 | 0.25 | } | } | 15 | 30 | 25 | 5 20 | |
| | undamaged | stage | Adequate | 4.5 | 0.45 | 4.5 | 2.0 | 0.25 | | | 15 | 30 | 25 | 5 | |
| | leaf | | range | 6.0 | 0.80 | 6.0 | 4.0 | 0.60 | I | I | 25 | 20 | 35 | 10 | |
| | | | High | >6.0 | 0.80 | 0.9 | 4.0 | 0.60 | I | | 25 | 20 | 35 | 10 | - |
| | Oldest | Maturity | Deficient | < 3.5 | 0.40 | 4.0 | 1.8 | 0.30 | | | 15 | 20 | 30 | 5 | |
| | undamaged | | Adequate | 3.5 | 0.40 | 4.0 | 1.8 | 0.30 | I | I | 15 | 20 | 30 | 20 | |
| | leaf | | range | 3.5 | 09.0 | 6.0 | 3.0 | 0.40 | | I | 20 | 40 | 40 | 10 | |
| | | | High | >4.2 | 09.0 | 6.0 | 3.0 | 0.40 | | I | 20 | 40 | 40 | 10 | |
| Escarole | Oldest | 8-leaf | Deficient | < 4.2 | 0.45 | 5.7 | 1.7 | 0.25 | I | I | 15 | 30 | 20 | 4 | |
| | undamaged | stage | Adequate | 4.2 | 0.45 | 5.7 | 1.7 | 0.25 | | I | 15 | 30 | 20 | 4 | |
| | leaf | | range | 5.0 | 09.0 | 6.5 | 2.5 | 0.35 | | I | 25 | 20 | 30 | 9 | |
| | | | High | >5.0 | 0.60 | 6.5 | 2.5 | 0.35 | I | I | 25 | 20 | 30 | 9 | |
| | Oldest | Maturity | Deficient | <3.0 | 0.35 | 5.5 | 2.0 | 0.25 | I | I | 15 | 20 | 30 | 4 | 1 |
| | undamaged | | Adequate | 3.0 | 0.35 | 5.5 | 2.0 | 0.25 | | | 15 | 20 | 30 | 4 | |
| | leaf | | range | 4.5 | 0.45 | 6.5 | 3.0 | 0.35 | 1 | I | 25 | 20 | 45 | 9 | |
| | | | High | >4.5 | 0.45 | 6.5 | 3.0 | 0.35 | I | | 25 | 20 | 45 | 9 | - |
| Lettuce, | Oldest | 8-leaf | Deficient | < 4.0 | 0.40 | 5.0 | 1.0 | 0.40 | | 20 | 10 | 40 | 15 | 5 | 0.1 |
| Boston | undamaged | stage | Adequate | 4.0 | 0.40 | 5.0 | 1.7 | 0.40 | 1 | 20 | 10 | 40 | 15 | က | 0.1 |

| 0.2 | 0.4 | | 0.1 | 0.1 | 0.2 | 0.4 | | | | | | | | | | | | | | | | | | | | | |
|-------|------|-----------|-----------|-----------|-------|------|-----|-----------|-----------|------|------|-----------|-----------|------|------|----------|-----------|------|------|---------|--------------------|------|------|----------|----------|-------|------|
| 10 | 10 | 1 | ល | ល | 10 | 10 | | ល | ro | 10 | 10 | 50 | ល | 10 | 10 | ល | ro | 10 | 10 | ស | ស | 10 | 10 | 50 | ις. | 10 | 10 |
| 25 | 25 | 100 | 15 | 15 | 25 | 25 | 100 | 20 | 20 | 40 | 40 | 20 | 20 | 40 | 40 | 15 | 15 | 30 | 30 | 15 | 15 | 30 | 30 | 15 | 15 | 30 | 30 |
| 09 | 09 | 1 | 20 | 20 | 40 | 40 | | 40 | 40 | 09 | 09 | 20 | 20 | 40 | 40 | 25 | 22 | 20 | 20 | 25 | 25 | 20 | 20 | 25 | 25 | 20 | 20 |
| 20 | 20 | 250 | 10 | 10 | 20 | 20 | 250 | 10 | 10 | 20 | 20 | 10 | 10 | 20 | 20 | 20 | 20 | 40 | 40 | 20 | 20 | 40 | 40 | 20 | 20 | 40 | 40 |
| 100 | 100 | I | 20 | 20 | 100 | 100 | I | 40 | 40 | 100 | 100 | 20 | 20 | 20 | 20 | 20 | 20 | 150 | 150 | 20 | 20 | 150 | 150 | 20 | 20 | 150 | 150 |
| ١ | I | I | | I | I | | | I | I | I | I | I | I | I | I | 0.30 | | 0.50 | I | I | 0.30 | 0.50 | I | I | 0.30 | 0.50 | 1 |
| 09.0 | 0.60 | I | 0.30 | 0.30 | 09.0 | 09.0 | I | 0.30 | 0.30 | 1.70 | 1.70 | 0.30 | 0.30 | 0.70 | 0.70 | 0.30 | 0.30 | 0.50 | 0.50 | 0.30 | 0.30 | 0.70 | 0.70 | 0.30 | 0.30 | 0.70 | 0.70 |
| 2.0 | 2.0 | 1 | 1.0 | 1.7 | 2.0 | 2.0 | | 1.7 | 1.7 | 2.0 | 2.0 | 1.7 | 1.7 | 2.0 | 2.0 | 1.0 | 1.0 | 2.0 | 2.0 | 1.4 | 1.4 | 2.0 | 2.0 | 1.4 | 1.4 | 2.0 | 2.0 |
| 0.9 | 0.9 | I | 5.0 | 5.0 | 0.9 | 0.9 | | 4.0 | 4.0 | 6.0 | 0.9 | 4.0 | 4.0 | 0.9 | 0.9 | 5.0 | 5.0 | 7.0 | 7.0 | 4.5 | 4.5 | 8.0 | 8.0 | 2.5 | 2.5 | 5.0 | 5.0 |
| 09.0 | 09.0 | I | 0.35 | 0.35 | 0.45 | 0.45 | | 0.50 | 0.50 | 09.0 | 09.0 | 0.40 | 0.40 | 09.0 | 09.0 | 0.40 | 0.40 | 09.0 | 09.0 | 0.40 | 0.40 | 09.0 | 09.0 | 0.25 | 0.25 | 0.50 | 0.50 |
| 6.0 | >6.0 | I | <3.0 | 3.0 | 4.0 | >4.0 | I | <4.0 | 4.0 | 5.0 | >5.0 | <3.0 | 3.0 | 4.0 | >4.0 | <4.0 | 4.0 | 5.0 | >5.0 | <2.5 | 2.5 | 4.0 | >4.0 | <2.0 | 2.0 | 3.0 | >3.0 |
| range | High | Toxic (>) | Deficient | Adequate | range | High | | Deficient | | | | Deficient | | | | | | | | | 4) | | | | Adequate | range | High |
| | | | Maturity | | | | | 8-leaf | stage | | | Maturity | | | | 8-leaf | stage | | | Heads | $\frac{1}{2}$ size | | | Maturity | | | |
| leaf | | | Oldest | undamaged | leaf | | | Oldest | undamaged | leaf | | Oldest | undamaged | leaf | | MRM | | | | Wrapper | leaf | | | Wrapper | leaf | | |
| | | | | | | | | Lettuce, | cos | | | | | | | Lettuce, | crisphead | | | | | | | | | | |

TABLE 4.25. CRITICAL (DEFICIENCY) VALUES, ADEQUATE RANGES, HIGH VALUES, AND TOXICITY VALUES FOR PLANT NUTRIENT CONCENTRATION OF VEGETABLES (Continued)

| | Mo | I | | I | I | 0.1 | 0.1 | 0.4 | I | I | | | I | | | I | I | | I | I |
|-----|---------------------|-----------|-----------|-------|------|-----------|-----------|-------|------|-----------|---------------|-------|------|-----------|------------|-------|------|------------|----------|------------|
| | Cu | rc | v. | 10 | 10 | 70 | 70 | 10 | 10 | 70 | 70 | 10 | 10 | 70 | 70 | 10 | 10 | 70 | 70 | 10 |
| я | В | 30 | 30 | 45 | 45 | 30 | 30 | 45 | 45 | 25 | 25 | 20 | 50 | 25 | 25 | 20 | 20 | 10 | 10 | 25 |
| mdd | Zn | 0.0 | 20 | 20 | 20 | 20 | 20 | 20 | 50 | 30 | 30 | 20 | 50 | 30 | 30 | 20 | 20 | 15 | 15 | 20 |
| | Mn | ŕc | 15 | 25 | 25 | 15 | 15 | 25 | 25 | 30 | 30 | 100 | 100 | 30 | 30 | 100 | 100 | 10 | 10 | 20 |
| | Fe | I | - | | | | | | | 50 | 20 | 100 | 100 | 20 | 20 | 100 | 100 | | | |
| | ∞ | I | I | | 1 | | | | 1 | | | | | | | | | 0.20 | 0.20 | 0.60 |
| | Mg | 0.25 | 0.25 | 0.35 | 0.35 | 0.25 | 0.25 | 0.40 | 0.40 | 0.25 | 0.25 | 0.50 | 0.50 | 0.25 | 0.25 | 0.50 | 0.50 | 0.15 | 0.15 | 0.30 |
| _ | Ca | 0.0 | 2.0 | 3.0 | 3.0 | 2.0 | 2.0 | 3.0 | 3.0 | 0.5 | 0.5 | 8.0 | 8.0 | 1.0 | 1.0 | 1.5 | 1.5 | 9.0 | 9.0 | 8.0 |
| % | K | 0 | 5.0 | 6.0 | 0.9 | 5.0 | 5.0 | 0.9 | 0.9 | 2.0 | 2.0 | 3.0 | 3.0 | 2.0 | 2.0 | 3.0 | 3.0 | 1.5 | 1.5 | 3.0 |
| | д | 0.35 | 0.35 | 0.80 | 0.80 | 0.35 | 0.35 | 09.0 | 09.0 | 0.30 | 0.30 | 09.0 | 09.0 | 0.30 | 0.30 | 09.0 | 09.0 | 0.20 | 0.20 | 0.50 |
| | z | , re | 5.0 | 6.0 | >6.0 | <3.5 | 3.5 | 4.5 | >4.5 | <3.5 | 3.5 | 5.0 | >5.0 | <2.5 | 2.5 | 3.0 | >3.0 | <2.0 | 2.0 | 3.0 |
| | Status | Deficient | Adequate | range | High | Deficient | Adequate | range | High | Deficient | Adequate | range | High | Deficient | Adequate | range | High | Deficient | Adequate | range |
| | Time of Sampling | 8-leaf | stage |) | | Maturity | | | | 30 days | after seeding | | | Prior | to harvest | | | Just prior | to bulb | initiation |
| | $\rm Plant\ Part^1$ | Oldest | undamaged | leaf | | Oldest | undamaged | leaf | | MRM | leaf | | | MRM | leaf | | | MRM | | |
| | Crop | Lettinge | romaine | | | | | | | Okra | | | | | | | | Onion, | sweet | |

| | ı | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 0.1 | 0.1 | 0.2 | 1 | 1 | 0.1 | 0.1 | 0.2 | 1 | 0.1 |
|------|-----------|-----------|------------|-------|-------|-----------|-----------|----------|-------|-------|-----------|-------------|----------|-------|------|-----------|------------|----------|-------|------|-----------|-----------|---------------|-------|------|-----------|
| 10 | I | ъ | ro | 10 | 10 | | က | ъ | 10 | 10 | I | ro | က | 10 | 10 | I | က | ro | 10 | 10 | I | ъ | က | 10 | 10 | 5 |
| 25 | 100 | 20 | 20 | 20 | 20 | 350 | 20 | 20 | 20 | 20 | 350 | 20 | 20 | 20 | 20 | 350 | 20 | 20 | 20 | 20 | 350 | 20 | 20 | 09 | 09 | 20 |
| 20 | I | 25 | 25 | 80 | 80 | | 25 | 25 | 80 | 80 | 1 | 25 | 25 | 80 | 80 | I | 25 | 25 | 80 | 80 | I | 30 | 30 | 09 | 09 | 30 |
| 20 | I | 30 | 30 | 100 | 100 | 1 | 30 | 30 | 100 | 100 | 1000 | 30 | 30 | 100 | 100 | I | 30 | 30 | 100 | 100 | 1 | 30 | 30 | 09 | 09 | 30 |
| 1 | I | 30 | 30 | 150 | 150 | | 30 | 30 | 150 | 150 | | 30 | 30 | 150 | 150 | I | 30 | 30 | 150 | 150 | | 40 | 40 | 150 | 150 | 40 |
| 0.60 | 1 | 0.30 | 0.30 | 0.60 | 0.60 | | 0.30 | 0.30 | 0.60 | 0.60 | | 0.30 | 0.30 | 0.40 | 0.40 | | 0.30 | 0.30 | 0.40 | 0.40 | | 0.25 | 0.25 | 0.50 | 0.50 | 0.20 |
| 0.30 | I | 0.35 | 0.35 | 09.0 | 09.0 | I | 0.30 | 0.30 | 0.50 | 0.50 | I | 0.30 | 0.30 | 0.40 | 0.40 | I | 0.30 | 0.30 | 0.40 | 0.40 | I | 0.30 | 0.30 | 0.60 | 09.0 | 0.25 |
| 8.0 | I | 6.0 | 6.0 | 1.5 | 1.5 | | 6.0 | 6.0 | 1.5 | 1.5 | I | 1.0 | 1.0 | 1.5 | 1.5 | I | 1.0 | 1.0 | 1.5 | 1.5 | I | 0.6 | 0.0 | 2.0 | 2.0 | 9.0 |
| 3.0 | I | 5.0 | 5.0 | 0.9 | 0.9 | | 2.5 | 2.5 | 5.0 | 5.0 | | 2.5 | 2.5 | 4.0 | 4.0 | I | 2.0 | 2.0 | 3.0 | 3.0 | | 3.5 | 3.5 | 6.0 | 0.9 | 3.0 |
| 0.50 | I | 0.30 | 0.30 | 0.50 | 0.50 | | 0.30 | 0.30 | 0.50 | 0.50 | | 0.25 | 0.25 | 0.40 | 0.40 | I | 0.20 | 0.20 | 0.40 | 0.40 | | 0.20 | 0.20 | 0.80 | 0.80 | 0.20 |
| >3.0 | I | <4.0 | 4.0 | 5.0 | > 5.0 | 1 | <3.0 | 3.0 | 5.0 | > 5.0 | I | <2.9 | 2.9 | 4.0 | >4.0 | I | $<\!\!2.5$ | 2.5 | 3.0 | >3.0 | 1 | <3.0 | 3.0 | 6.0 | >6.0 | <3.0 |
| High | Toxic (>) | Deficient | Adequate | range | High | Toxic (>) | Deficient | Adequate | range | High | Toxic (>) | Deficient | Adequate | range | High | Toxic (>) | Deficient | Adequate | range | High | Toxic (>) | Deficient | Adequate | range | High | Deficient |
| | | Prior to | blossoming | | | | First | plossoms | oben | | | Early fruit | set | | | | Early | harvest | | | | Plants | 8–10 in. tall | | | First |
| | | MRM | leaf | | | | MRM | leaf | | | | MRM | leaf | | | | MRM | leaf | | | | MRM | leaf | | | MRM |

TABLE 4.25. CRITICAL (DEFICIENCY) VALUES, ADEQUATE RANGES, HIGH VALUES, AND TOXICITY

| | VALUES F | VALUES FOR PLANT NUTRIENT CONCENTRATION OF VEGETABLES (Continued) | TRIENT C | ONC | ENTE | RATIO | O NC | F VE | GETA | BLE | S (Cor | ıtinu | eq) | | |
|---------|---------------------|---|-----------|-------|------|-------|------|------|------|-----|--------|-------|-----|----|-----|
| | | | | | | 8 | % | | | | | wdd | а | | |
| Crop | ${ m Plant~Part}^1$ | Time of Sampling | Status | Z | Ъ | × | Ca | Mg | w | Fe | Mn | Zn | В | Cu | Mo |
| | leaf | plossom | Adequate | 3.0 | 0.20 | 3.0 | 0.6 | 0.25 | 0.20 | 40 | 30 | 30 | 20 | ro | 0.1 |
| | | | range | 4.0 | 0.50 | 5.0 | 2.0 | 09.0 | 0.50 | 150 | 100 | 09 | 30 | 10 | 0.2 |
| | | | High | >4.0 | 0.50 | 5.0 | 2.0 | 0.60 | 0.50 | 150 | 100 | 09 | 30 | 10 | 1 |
| | MRM | Tubers | Deficient | < 2.0 | 0.20 | 2.5 | 9.0 | 0.25 | 0.20 | 40 | 20 | 30 | 20 | 70 | 0.1 |
| | leaf | $^{1/_{2}}$ grown | Adequate | 2.0 | 0.20 | 2.5 | 9.0 | 0.25 | 0.20 | 40 | 20 | 30 | 20 | 70 | 0.1 |
| | | | range | 4.0 | 0.40 | 4.0 | 2.0 | 0.60 | 0.50 | 150 | 100 | 09 | 30 | 10 | 0.2 |
| | | | High | >4.0 | 0.40 | 4.0 | 2.0 | 0.60 | 0.50 | 150 | 100 | 09 | 30 | 10 | |
| | MRM | At tops-down | Deficient | < 2.0 | 0.16 | 1.5 | 9.0 | 0.20 | 0.20 | 40 | 20 | 30 | 20 | 70 | 0.1 |
| | leaf | | Adequate | 2.0 | 0.16 | 1.5 | 9.0 | 0.20 | 0.20 | 40 | 20 | 30 | 20 | 70 | 0.1 |
| | | | range | 3.0 | 0.40 | 3.0 | 2.0 | 0.50 | 0.50 | 150 | 100 | 09 | 30 | 10 | 0.2 |
| | | | High | >3.0 | 0.40 | 3.0 | 2.0 | 0.50 | 0.50 | 150 | 100 | 09 | 30 | 10 | |
| Pumpkin | MRM | 5 weeks | Deficient | <3.0 | 0.30 | 2.3 | 0.9 | 0.35 | 0.20 | 40 | 40 | 20 | 25 | 50 | 0.3 |
| | leaf | after seeding | Adequate | 3.0 | 0.30 | 2.3 | 0.9 | 0.35 | 0.20 | 40 | 40 | 20 | 25 | 5 | 0.3 |
| | | | range | 6.0 | 0.50 | 4.0 | 1.5 | 0.60 | 0.40 | 100 | 100 | 20 | 40 | 10 | 0.5 |
| | | | High | >6.0 | 0.50 | 4.0 | 1.5 | 0.60 | 0.40 | 100 | 100 | 20 | 40 | 10 | |
| | MRM | 8 weeks from | Deficient | <3.0 | 0.25 | 2.0 | 0.9 | 0.30 | 0.20 | 40 | 40 | 20 | 20 | ю | 0.3 |
| | leaf | seeding | Adequate | 3.0 | 0.25 | 2.0 | 0.9 | 0.30 | 0.20 | 40 | 40 | 20 | 20 | 20 | 0.3 |
| | | | range | 4.0 | 0.40 | 3.0 | 1.5 | 0.50 | 0.40 | 100 | 100 | 20 | 40 | 10 | 0.5 |
| | | | | | | | | | | | | | | | |

| Radish | MRM | At harvest | High Deficient | >4.0 | 0.40 | 3.0 | $\frac{1.5}{1.0}$ | 0.50 | 0.40 | 100 30 | 100 | 50 30 | 15 | 0 6 | 0.1 |
|------------|------|---------------|-------------------|------|------|-----|-------------------|------|------|-----------|-----|----------|----|------|-----|
| | leaf | | Adequate | 3.0 | 0.25 | 1.5 | 1.0 | 0.30 | I | 30 | 20 | 30 | 15 | ಣ | 0.1 |
| | | | range | 4.5 | 0.40 | 3.0 | 2.0 | 0.50 | | 20 | 40 | 20 | 30 | 0] | 2.0 |
| | | | High | >4.5 | 0.40 | 3.0 | 2.0 | 0.50 | I | 20 | 40 | 20 | 30 | 0] | 2.0 |
| | | | Toxic (>) | | I | 1 | 1 | I | I | | | ı | 85 | 1 | ı |
| Southern | MRM | Before bloom | Deficient | <3.5 | 0.30 | 2.0 | 1.0 | 0.30 | I | 30 | 30 | 20 | 15 | ت | ı |
| pea | leaf | | Adequate | 3.5 | 0.30 | 2.0 | 1.0 | 0.30 | I | 30 | 30 | 20 | 15 | ت | ı |
| | | | range | 5.0 | 08.0 | 4.0 | 1.5 | 0.50 | I | 100 | 100 | 40 | 25 | . 01 | 1 |
| | | | High | >5.0 | 08.0 | 4.0 | 1.5 | 0.50 | I | 100 | 100 | 40 | 25 | . 0] | ı |
| | MRM | First bloom | Deficient | <2.5 | 0.20 | 2.0 | 1.0 | 0.30 | I | 30 | 30 | 20 | 15 | ro | 4.0 |
| | leaf | | Adequate | 2.5 | 0.20 | 2.0 | 1.0 | 0.30 | I | 30 | 30 | 20 | 15 | າວ | 4.0 |
| | | | range | 4.0 | 0.40 | 4.0 | 1.5 | 0.50 | | 100 | 100 | 40 | 52 | 0] | 0.9 |
| | | | High | >4.0 | 0.40 | 4.0 | 1.5 | 0.50 | I | 100 | 100 | 40 | 25 | 0] | 0.9 |
| Spinach | MRM | 30 days | Deficient | <3.0 | 0.30 | 3.0 | 9.0 | 1.00 | I | I | 20 | 20 | 20 | ro | 0.1 |
| | leaf | after seeding | Adequate | 3.0 | 0.30 | 3.0 | 9.0 | 1.00 | I | I | 20 | 20 | 20 | ນ | 0.1 |
| | | | range | 4.5 | 0.50 | 4.0 | 1.0 | 1.60 | I | I | 100 | 20 | 40 | 2 | 1.0 |
| | | | High | >5.0 | 0.50 | 4.0 | 1.0 | 1.60 | I | I | 100 | 20 | 40 | 7 | 1.0 |
| | MRM | Harvest | Deficient | <3.0 | 0.25 | 2.5 | 9.0 | 1.00 | I | I | 30 | 20 | 20 | ນ | 0.1 |
| | leaf | | Adequate | 3.0 | 0.25 | 2.5 | 9.0 | 1.00 | I | I | 30 | 20 | 20 | 20 | 0.1 |
| | | | range | 4.0 | 0.50 | 3.5 | 1.0 | 1.60 | I | | 20 | 20 | 40 | 7 | 1.0 |
| | | | High | >4.0 | 0.50 | 4.0 | 1.0 | 1.60 | I | | 80 | 20 | 40 | 7 | 1.0 |
| Squash | MRM | Early fruit | Deficient | <3.0 | 0.25 | 2.0 | 1.0 | 0.30 | 0.20 | 40 | 40 | 20 | 25 | ນ | 0.3 |
| | | | Adequate | 3.0 | 0.25 | 2.0 | 1.0 | 0.30 | 0.20 | 40 | 40 | 20 | 25 | ro | 0.3 |
| | | | range | 5.0 | 0.50 | 3.0 | 2.0 | 0.50 | 0.50 | 100 | 100 | 20 | 40 | 02 | 0.5 |
| | | | High | >5.0 | 0.50 | 3.0 | 2.0 | 0.50 | 0.50 | 100 | 100 | 20 | 40 | 02 | 0.5 |
| Strawberry | MRM | Transplants | Deficient | <2.8 | 0.25 | 1.5 | 0.3 | 0.30 | I | 20 | 30 | 25 | 25 | تن | 1 |
| | leaf | | Adequate | 2.8 | 0.25 | 1.5 | 0.3 | 0.30 | I | 50 | 30 | 25 | 25 | 5 | ı |
| | | | range | 3.5 | 0.40 | 3.0 | 1.5 | 09.0 | | 100 | 100 | 40 | 40 | | ı |

TABLE 4.25. CRITICAL (DEFICIENCY) VALUES, ADEQUATE RANGES, HIGH VALUES, AND TOXICITY VALUES FOR PLANT NUTRIENT CONCENTRATION OF VEGETABLES (Continued)

| | Mo | I | | | | 1 | | | 1 | | | 0.5 | 0.5 | 8.0 | 0.8 | | | | | |
|-----|-------------------------|------|-----------|----------|-------|------|-----------|----------|-------|------|-----------|-----------|----------|-------|------|-----------|-----------|----------|-------|------|
| | Cu | 10 | ಸರ | ည | 10 | 10 | 5 | 50 | 10 | 10 | | ಸರ | 5 | 10 | 10 | | 50 | 20 | 10 | 10 |
| | В | 40 | 20 | 20 | 40 | 20 | 20 | 20 | 40 | 40 | | 20 | 20 | 40 | 40 | | 20 | 20 | 40 | 40 |
| mdd | Zn | 40 | 20 | 20 | 40 | 40 | 20 | 20 | 40 | 40 | I | 20 | 20 | 40 | 40 | | 20 | 20 | 40 | 40 |
| | Mn | 100 | 30 | 30 | 100 | 100 | 30 | 30 | 100 | 100 | 800 | 25 | 25 | 100 | 100 | 800 | 25 | 25 | 100 | 100 |
| | Fe | 100 | 20 | 20 | 100 | 100 | 50 | 20 | 100 | 100 | 1 | 20 | 50 | 100 | 100 | | 20 | 50 | 100 | 100 |
| | ∞ | | | | | | | | I | | | 0.8 | 0.8 | 1.0 | 1.0 | | | | | |
| | Mg | 09.0 | 0.25 | 0.25 | 0.50 | 0.50 | 0.25 | 0.25 | 0.50 | 0.50 | I | 0.20 | 0.20 | 0.40 | 0.40 | I | 0.20 | 0.20 | 0.40 | 0.40 |
| | Ca | 1.5 | 0.4 | 0.4 | 1.5 | 1.5 | 0.4 | 0.4 | 1.5 | 1.5 | I | 0.4 | 0.4 | 1.5 | 1.5 | I | 0.4 | 0.4 | 1.5 | 1.5 |
| % | X | 3.0 | 1.5 | 1.5 | 3.0 | 3.0 | 1.5 | 1.5 | 2.5 | 2.5 | I | 1.1 | 1:1 | 2.5 | 2.5 | | 1:1 | 1.1 | 2.0 | 2.0 |
| | Ь | 0.40 | 0.20 | 0.20 | 0.40 | 0.40 | 0.20 | 0.20 | 0.40 | 0.40 | I | 0.20 | 0.20 | 0.40 | 0.40 | I | 0.20 | 0.20 | 0.30 | 0.30 |
| | Z | >3.5 | <3.0 | 3.0 | 4.0 | >4.0 | <3.0 | 3.0 | 3.5 | >3.5 | 1 | <2.8 | 2.8 | 3.0 | >3.0 | | <2.5 | 2.5 | 3.0 | >3.0 |
| | Status | High | Deficient | Adequate | range | High | Deficient | Adequate | range | High | Toxic (>) | Deficient | Adequate | range | High | Toxic (>) | Deficient | Adequate | range | High |
| | Time of Sampling | | Initial | flower | | | Initial | harvest | | | | Midseason | | | | | End of | season | | |
| | Plant Part ¹ | | MRM | leaf | | | MRM | leaf | | | | MRM | leaf | | | | MRM | leaf | | |
| | Crop | | | | | | | | | | | | | | | | | | | |

| 0.1 0.2 0.2 | 0.1 0.2 0.2 | 0.1 0.2 0.2 | 0.1 0.2 0.2 | 0.1 0.1 0.2 | 1 1 1 |
|---|------------------------------|---------------------------------|------------------------------|---|----------------------|
| 10 10 1 | 10 10 1 | 4 4 10 10 | 4 4 10 10 | 4 4 10 110 110 | 5 10 |
| 10 10 30 30 100 | 10 10 30 30 100 | 10 10 30 30 100 | 10 10 20 20 100 | 10 10 20 20 | 20 20 50 |
| 30 30 40 40 | 30 30 40 40 | 25 25 40 40 | 20 20 40 40 | 20 20 40 40 | 25 25 50 |
| 40 40 100 100 | 40 40 100 100 | 40 40 100 100 | 30 30 100 100 | 20 20 100 100 | 40 40 100 |
| 50 50 100 100 | 50 50 100 100 | 40 100 100 1 | 30 30 100 100 | 30 30 100 100 | 40 40 100 |
| 0.4 0.6 0.6 | 0.4 0.6 0.6 | 0.2 0.4 4.0 | 0.2 0.2 0.4 0.4 | 0.20 0.20 0.40 0.40 | 0.20 0.20 0.60 |
| 0.25 0.25 0.50 0.50 | 0.25 0.25 0.50 0.50 | 0.20 0.20 0.40 0.40 | 0.15 0.15 0.40 0.40 | 0.15 0.15 0.40 0.40 | 0.40 0.40 0.80 |
| 0.6 0.8 0.8 0.8 | 0.5 0.8 0.8 0.8 0.8 | 0.5 0.8 0.8 0.8 | 0.3 0.6 0.6 0.6 0.6 | 0.3 (0.3 (0.6 (0.6 (0.6 (0.6 (0.6 (0.6 (0.6 (0.6 | 0.8 (0.8 (1.6 (|
| 22.5 7.5.5 1.0 1.0 | 2.5 2.5 4.0 1.0 | 2.5 2.5 6.0 1.0 1.0 | 2.0 2.0 3.5 1 | 1.2 2.2 2.0 2.0 | 2.5 2.5 4.0 |
| 0.35 0.50 0.50 | 0.25 0.25 0.50 | 0.20 0.40 0.40 | 0.20 0.40 0.40 | 0.20 0.20 0.40 | 0.30 |
| | | | | <pre><1.5 (1.5 (2.5 (>2.5 (>2.5 ()</pre> | |
| Deficient Adequate range High Toxic (>) | 0 - | | | Deficient <adequate high<="" range="" td=""><td>ent aate ge</td></adequate> | ent aate ge |
| 3-leaf stage | 6-leaf stage | 30 in. tall | Just prior to tassel | Tasseling | Early vining |
| Whole seedlings | Whole seedlings | MRM leaf | MRM leaf | Ear leaf | MRM leaf |
| Sweet corn | | | | | Sweet |

TABLE 4.25. CRITICAL (DEFICIENCY) VALUES, ADEQUATE RANGES, HIGH VALUES, AND TOXICITY VALUES FOR PLANT NUTRIENT CONCENTRATION OF VEGETABLES (Continued)

| | Cu Mo | 10 — | 5 | 5 | 10 — | 10 — | L | ဂ | o 70 | 10 10 | 10 10 10 10 10 10 10 10 10 10 10 10 10 1 | 5 - 10 - 10 - 10 - 10 - 10 - 10 - 10 - 1 | 5 | 10 10 10 10 10 10 10 10 10 10 10 10 10 1 | 10 10 10 10 10 10 10 10 10 10 10 10 10 1 | 10 10 10 10 10 10 10 10 10 10 10 10 10 1 | 10 10 10 10 10 10 10 10 10 10 10 10 10 1 | 10 - 10 - 10 - 10 - 10 - 10 - 10 - 10 - | 10 10 10 10 11 11 11 11 11 11 11 11 11 1 | 10 10 10 10 10 10 10 10 10 10 10 10 10 1 |
|-----|-------------------------|------|-----------|-------------|-------------|------|-----------|-------------|------|-----------|--|--|--|--|---|---|--|--|--|---|
| mdd | В | 50 | 25 | 25 | 40 | 40 | 20 | | 20 | | | | | | | | | | | |
| þŗ | Zn | 50 | 25 | 25 | 40 | 40 | 25 | | 25 | •• -• | | | | | | | | | | |
| | Mn | 100 | 40 | 40 | 100 | 100 | 40 | | 40 | 40 100 | 40 100 100 | 40 100 100 40 | 40 100 100 40 40 | 40 100 100 40 40 | 40 100 100 40 40 100 | 40 100 100 40 40 100 100 | 40 100 100 40 40 40 100 100 30 | 40 100 100 40 40 100 100 30 30 | 40 100 100 40 40 100 100 30 30 100 100 | 40 100 100 40 40 100 100 30 30 100 100 100 30 |
| | Fe | 100 | 40 | 40 | 100 | 100 | 40 | | 40 | 40 | 40 100 100 | 40 100 100 40 | 40 100 100 40 40 | 40 100 100 40 40 | 40 100 100 40 40 100 | 40 100 100 40 40 100 100 | 40 100 100 40 100 100 40 40 | 40 100 100 40 100 100 40 40 | 40 100 100 40 40 100 100 40 40 100 | 40 100 100 40 100 100 40 40 40 |
| | ∞ | 09.0 | 0.20 | 0.20 | 0.40 | 0.40 | 0.20 | 0 | 0.70 | 0.20 | 0.20 | 0.20 0.60 0.60 0.20 | 0.20 0.60 0.60 0.20 0.20 | 0.20 0.60 0.20 0.20 0.20 | 0.20 0.60 0.20 0.20 0.60 0.60 | 0.20 0.60 0.20 0.20 0.60 0.60 | 0.20 0.60 0.20 0.20 0.20 0.60 0.60 0.30 | 0.20 0.60 0.20 0.20 0.20 0.60 0.60 0.30 0.30 | 0.20 0.60 0.20 0.20 0.20 0.60 0.60 0.30 0.30 0.80 | 0.20 0.60 0.60 0.20 0.20 0.20 0.30 0.30 0.80 0.30 |
| | Mg | 0.80 | 0.25 | 0.25 | 0.50 | 0.50 | 0.25 | 30.0 | 0.7 | 0.50 | 0.50 | 0.50 0.50 0.25 | 0.25 0.50 0.50 0.25 0.25 | 0.25 0.25 0.25 0.25 0.25 | 0.50 0.50 0.25 0.25 0.50 0.50 | 0.50 0.50 0.25 0.25 0.50 0.50 | 0.50 0.25 0.25 0.25 0.50 0.50 0.30 | 0.50 0.50 0.25 0.25 0.50 0.50 0.30 0.30 | 0.50 0.50 0.25 0.25 0.50 0.50 0.30 0.50 | 0.50 0.50 0.50 0.50 0.50 0.50 0.50 0.50 |
| % | Ca | 1.6 | 0.8 | 0.8 | 1.8 | 1.8 | 0.8 | 00 | ; | 1.6 | 1.6 | 1.6 | 1.6 1.6 0.8 0.8 | 1.6 1.6 0.8 0.8 1.6 | 1.6 1.6 0.8 0.8 1.6 | 1.6 1.6 0.8 0.8 1.6 1.6 | 1.6 0.8 0.8 1.6 1.6 1.0 | 1.6 0.8 0.8 0.8 1.6 1.0 1.0 1.0 2.0 | 1.6 0.8 0.8 0.8 0.8 1.6 1.0 1.0 1.0 2.0 2.0 | 1.6 0.8 0.8 0.8 1.6 1.0 1.0 2.0 2.0 2.0 1.00 |
| 6 | × | 4.0 | 2.0 | 2.0 | 4.0 | 4.0 | 2.0 | 2.0 | | 4.0 | 4.0 | 4.0 2.0 | 4.0 2.0 2.0 | 0.4.0 0.2.0 4.0 4.0 | 0.4.0 0.2.0 0.4.0 0.4.0 | 0.4.4.0 0.2.0.4.4.0 0.3.0 0.3.0 | 4.0 2.0 2.0 2.0 4.0 4.0 3.0 3.0 | 0.4, 4, 2, 2, 2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, | 4. 4. 2. 2. 4. 4. 2. 2. 2. 7. 7. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. | 4. 4. 2. 2. 4. 4. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. |
| | Д | 0.50 | 0.20 | 0.20 | 0.30 | 0.30 | 0.20 | 0.20 | | 0.30 | 0.30 | 0.30 0.30 0.20 | 0.30 0.30 0.20 0.20 | 0.30 0.30 0.20 0.20 0.30 | 0.30 0.20 0.20 0.30 0.30 | 0.30 0.20 0.20 0.20 0.30 0.30 | 0.30 0.20 0.20 0.20 0.30 0.30 | 0.30 0.20 0.20 0.20 0.30 0.30 0.30 0.30 | 0.30 0.20 0.20 0.20 0.30 0.30 0.30 0.60 | 0.30 0.20 0.20 0.20 0.30 0.30 0.30 0.60 0.60 |
| | Z | >5.0 | <3.0 | 3.0 | 4.0 | >4.0 | <3.0 | 3.0 | | 4.0 | 4.0 >4.0 | 4.0 >4.0 <2.8 | 4.0 7.2.8 2.8 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| | Status | High | Deficient | Adequate | range | High | Deficient | Adequate | | range | range High | range High Deficient | range High Deficient Adequate | range High Deficient Adequate range | range High Deficient Adequate range High | range High Deficient Adequate range High | range High Deficient Adequate range High Deficient | range High Deficient Adequate range High Deficient Adequate range | range High Deficient Adequate range High Deficient Adequate range | range High Deficient Adequate range High Deficient Adequate range High Deficient |
| | Time of Sampling | | Midseason | before root | enlargement | | Root | enlargement | | | | Just before | Just before harvest | Just before harvest | Just before harvest | Just before harvest 5-leaf | Just before harvest 5-leaf stage | Just before harvest 5-leaf stage | Just before harvest 5-leaf stage | Just before harvest 5-leaf stage First |
| | Plant Part ¹ | | MRM | leaf | | | MRM | leaf | | | | MRM | MRM leaf | MRM leaf | MRM leaf | MRM leaf MRM | MRM leaf MRM leaf | MRM leaf MRM leaf | MRM leaf MRM leaf | MRM leaf MRM leaf MRM |
| | Crop | | | | | | | | | | | | | | | Tomato | Tomato | Tomato | Tomato | Tomato |

| 9.0 | 9.0 | | 0.5 | 0.5 | 9.0 | 9.0 | I | 0.2 | 0.5 | 9.0 | 9.0 | 0.5 | 0.5 | 9.0 | 9.0 | I | I | | I | I | | I | I | I | I | |
|-------|------|-----------|-----------|-----------|-------|------|-----------|------------|----------|-------|------|-----------|----------|--------|------|-----------|----------|----------|------|------------|----------|--------------|------|-----------|-----------|----------|
| 15 | 15 | 1 | က | 50 | 10 | 10 | 1 | ಸರ | က | 10 | 10 | က | 50 | 10 | 10 | 50 | ည | 10 | 10 | ည | 3 | 10 | 10 | | 50 | ಸ |
| 40 | 40 | 250 | 20 | 20 | 40 | 40 | 250 | 20 | 20 | 40 | 40 | 20 | 20 | 40 | 40 | 20 | 20 | 40 | 40 | 20 | 20 | 40 | 40 | I | 20 | 20 |
| 40 | 40 | 300 | 20 | 20 | 40 | 40 | I | 20 | 20 | 40 | 40 | 20 | 20 | 40 | 40 | 20 | 20 | 40 | 40 | 20 | 20 | 40 | 40 | | 20 | 20 |
| 100 | 100 | 1500 | 30 | 30 | 100 | 100 | I | 30 | 30 | 100 | 100 | 30 | 30 | 100 | 100 | 30 | 30 | 100 | 100 | 20 | 20 | 100 | 100 | 800 | 20 | 20 |
| 100 | 100 | | 40 | 40 | 100 | 100 | I | 40 | 40 | 100 | 100 | 40 | 40 | 100 | 100 | 30 | 30 | 100 | 100 | 30 | 30 | 100 | 100 | | 30 | 30 |
| 0.80 | 0.80 | | 0.30 | 0.30 | 09.0 | 09.0 | I | 0.30 | 0.30 | 09.0 | 09.0 | 0.30 | 0.30 | 09.0 | 09.0 | 0.20 | 0.20 | 09.0 | 09.0 | 0.20 | 0.20 | 0.40 | 0.40 | I | 0.20 | 0.20 |
| 0.50 | 0.50 | 1 | 0.25 | 0.25 | 0.50 | 0.50 | I | 0.25 | 0.25 | 0.50 | 0.50 | 0.25 | 0.25 | 0.50 | 0.50 | 0.25 | 0.25 | 09.0 | 09.0 | 0.25 | 0.25 | 0.50 | 0.50 | I | 0.25 | 0.25 |
| 5.00 | 5.00 | | 1.0 | 1.0 | 2.0 | 2.0 | I | 1.0 | 1.0 | 2.0 | 2.0 | 1.0 | 1.0 | 2.0 | 2.0 | 8.0 | 8.0 | 1.5 | 1.5 | 1.0 | 1.0 | 2.0 | 2.0 | I | 1.0 | 1.0 |
| 4.0 | • • | | 2.5 | 2.5 | 4.0 | 4.0 | I | 2.0 | 2.0 | 4.0 | 4.0 | 1.5 | 1.5 | 2.5 | 2.5 | 2.5 | 2.5 | 4.0 | 4.0 | 3.0 | 3.0 | 4.0 | 4.0 | I | 2.7 | 2.7 |
| 0.40 | 0.40 | | 0.20 | 0.20 | 0.40 | 0.40 | I | 0.20 | 0.20 | 0.40 | 0.40 | 0.20 | 0.20 | 0.40 | 0.40 | 0.25 | 0.25 | 08.0 | 08.0 | 0.25 | 0.25 | 0.50 | 0.50 | I | 0.25 | 0.25 |
| | >4.0 | 1 | <2.5 | | | | 1 | | | | | | | | | | | | | | 3.0 | | | | <2.5 | |
| range | High | Toxic (>) | Deficient | Adequate | range | High | Toxic (>) | Deficient | Adequate | range | High | Deficient | Adequate | range | High | Deficient | Adequate | range | High | Deficient | Adequate | range | High | Toxic (>) | Deficient | Adequate |
| | | | Early | fruit set | | | | First ripe | fruit | | | During | harvest | period | | Hypocotyl | 1-in. | diameter | | Layby | (last | cultivation) | | | First | flower |
| | | | MRM | leaf | | | | MRM | leaf | | | MRM | leaf | | | MRM | leaf | | | on MRM | leaf | | | | MRM | leaf |
| | | | | | | | | | | | | | | | | Turnip | greens | | | Watermelon | | | | | | |

 M_0 CRITICAL (DEFICIENCY) VALUES, ADEQUATE RANGES, HIGH VALUES, AND TOXICITY Cn 70 10 10 20 20 40 40 VALUES FOR PLANT NUTRIENT CONCENTRATION OF VEGETABLES (Continued) М mdd 40 40 20 Z_{n} 8 20 20 8 001 Mn 00 00 200 Fe 0.40 0.40 0.200.20 0.40 മ 0.250.25 0.50 0.50Mg1.0 1.0 2.0 2.0 Ca 8 M 0.500.500.500.50 0.250.25Д >3.5 <2.0 >3.0 2.0 3.0 Z Adequate Deficient range Status range High Sampling Time of fruit First Plant Part¹ leaf MRM**TABLE 4.25.** Crop

Adapted from G. Hochmuth, D. Maynard, C. Vavrina, E. Hanlon, and E. Simonne, Plant Tissue Analysis and Interpretation for Vegetable Crops in Florida (Florida Cooperative Extension Service), http://edis.ifas.ufl.edu/hs162

20 20 40

20 20

20 001 001

0.200.20

0.250.250.50

1.0 1.0

0.250.25 0.50

<2.0

Deficient

2.0

Adequate

period Harvest

leaf MRM

range

200

0.40 0.40

0.50

100

¹MRM leaf is the most recently matured whole leaf blade plus petiole.

TABLE 4.26. UNIVERSITY OF FLORIDA GUIDELINES FOR LEAF PETIOLE FRESH SAP NITRATE-NITROGEN AND POTASSIUM TESTING

| | | | etiole Sap tion (ppm) |
|----------------|--|--|---|
| Стор | Development Stage/Time | NO_3 $-N$ | К |
| Eggplant | First fruit (2 in. long) First harvest Midharvest | 1,200–1,600 1,000–1,200 800–1,000 | 4,500–5,000 4,000–4,500 3,500–4,000 |
| Pepper | First flower buds First open flowers Fruits half-grown First harvest Second harvest | 1,400-1,600 1,400-1,600 1,400-1,600 1,200-1,400 800-1,000 500-800 | 3,200–3,500 3,000–3,200 3,000–3,200 2,400–3,000 2,000–2,400 |
| Potato | Plants 8 in. tall First open flowers 50% flowers open 100% flowers open | 1,200-1,400 1,000-1,400 1,000-1,200 900-1,200 | 4,500–5,000 4,500–5,000 4,000–4,500 3,500–4,000 |
| $Strawberry^1$ | Tops falling over November December January February March | 600–900 800–900 600–800 600–800 300–500 200–500 | 2,500-3,000 3,000-3,500 3,000-3,500 2,500-3,000 2,000-2,500 1,800-2,500 |
| Tomato | April First buds First open flowers Fruits 1-in. diameter Fruits 2-in. diameter | 200–500 200–500 1,000–1,200 600–800 400–600 | 1,500-2,500 1,500-2,000 3,500-4,000 3,500-4,000 3,000-3,500 3,000-3,500 |
| Watermelon | First harvest Second harvest Vines 6 in. long Fruit 2 in. long Fruits one-half mature At first harvest | 300-400 200-400 1,200-1,500 1,000-1,200 800-1,000 600-800 | 2,500–3,000 2,500–3,000 2,000–2,500 4,000–5,000 4,000–5,000 3,500–4,000 3,000–3,500 |

 $\label{lem:condition} Adapted from G. Hochmuth, "Plant Petiole Sap-testing Guide for Vegetable Crops," Florida Cooperative Extension Service Circular 1144 (2003), http://edis.ifas.ufl.edu/pdffiles/cv/cv00400.pdf. 1-Annual hill production system$

12 SOIL TESTS

Analyses for total amounts of nutrients in the soil are of limited value in predicting fertilizer needs. Consequently, various methods and extractants have been developed to estimate available soil nutrients and to serve as a basis for predicting fertilizer needs. Proper interpretation of the results of soil analysis is essential in recommending fertilizer needs. Soil testing procedure and extractants must be correlated with crop response to be of value for predicting crop need for fertilizer. One soil test procedure developed for one soil and crop condition in one area of the country may not apply in another area. Growers should consult their crop and soils experts about soil testing procedures appropriate for their growing area.

DETERMINING THE KIND AND QUANTITY OF FERTILIZER TO USE

Many states issue suggested rates of application of fertilizers for specific vegetables. These recommendations are sometimes made according to the type of soil—that is, light or heavy, sands, loams, clays, peats, and mucks. Other factors often used in establishing these rates are whether manure or soil-improving crops are employed and whether an optimum moisture supply can be maintained. The nutrient requirements of each crop must be considered, as must the past fertilizer and cropping history. The season of the year affects nutrient availability. Broad recommendations are at best only a point from which to make adjustments to suit individual conditions. Each field may require a different fertilizer program for the same vegetable.

Calibrated soil testing can provide an estimate of the concentration of essential elements that will be available to the crop during the season and predict the amount of fertilizer needed to produce a crop. Various extraction solutions are used by soil testing labs around the country to estimate the nutrient-supplying capacity of the soil, and not all solutions are calibrated for all soils. Therefore, growers must exercise care in selecting a lab to analyze soil samples, using only those labs that employ analytical procedures calibrated with yield response in specific soil types and growing regions. Even though several labs might differ in lab procedures, if all procedures are calibrated, then fertilizer recommendations should be similar. If unclear about specific soil testing practices, growers should consult their Cooperative Extension Service and the specific analytical lab.

Phosphorus. This element is not very mobile in most agricultural soils.Phosphorus is fixed in soils with basic reactions and large quantities of

calcium, or in acidic soils containing aluminum or iron. Even though phosphorus can be fixed, if a calibrated soil test predicts no response to phosphorus fertilization, then growers need not add large amounts of phosphorus because enough phosphorus will be made available to the crop during the growing season, even though the soil has a high phosphorus-fixing capacity. Sometimes crops might respond to small amounts of starter phosphorus supplied to high phosphorus testing soils in cold planting seasons.

Potassium. Although not generally considered a mobile element in soils, potassium can leach in coarse, sandy soils. Clay soils and loamy soils often contain adequate amounts of available potassium and may not need fertilization with potassium. Coarse, sandy soils usually test medium or low in extractable potassium, and crops growing on these soils respond to potassium fertilization.

Nitrogen. Most soil testing labs have no calibrated soil test for nitrogen because nitrogen is highly mobile in most soils and predicting a crop's response to nitrogen fertilization from a soil test is risky. However, some labs do predict the nitrogen-supplying capacity of a soil from a determination of soil organic matter. Estimates vary from 20 to 40 lb nitrogen made available during the season for each percent soil organic matter. Another soil nitrogen estimation procedure used by some labs is the pre-sidedress soil nitrate test. This test predicts the likelihood of need for sidedressed nitrogen during the season but is relatively insensitive for predicting exact amounts of sidedress nitrogen.

TABLE 4.27. PREDICTED RESPONSES OF CROPS TO RELATIVE AMOUNTS OF EXTRACTED PLANT NUTRIENTS BY SOIL TEST

| Soil Test Interpretation | Predicted Crop Response |
|--------------------------|--|
| Very high | No crop response predicted to fertilization with a particular element. |
| High | No crop response predicted to fertilization with a particular element. |
| Medium | 75–100% maximum expected yield predicted without fertilization. |
| Low | 50-75% maximum expected yield predicted without fertilization. |
| Very low | 25-50% maximum expected yield predicted without fertilization. |

BICARBONATE EXTRACTION METHOD, FOR POTASSIUM AND MAGNESIUM BY THE INTERPRETATION OF SOIL TEST RESULTS FOR PHOSPHORUS BY THE OLSEN AMMONIUM ACETATE EXTRACTION METHOD, AND FOR ZINC BY THE DPTA **TABLE 4.28.**

EXTRACTION METHOD

| | | Amount in Soil (ppm) | doil (ppm) | |
|---|--|---|--------------------------------|-----------------|
| Nutrient Need | $\begin{array}{c} \text{Phosphorus}^1 \\ (\text{PO}_4\text{-P}) \end{array}$ | $\begin{array}{c} \text{Potassium}^2 \\ \text{(K)} \end{array}$ | ${ m Magnesium}^2$ $({ m Mg})$ | $Zinc^3$ (Zn) |
| Deficient levels for most vegetables | 0-10 | 09-0 | 0-25 | 0-0.3 |
| Deficient for susceptible vegetables | 10-20 | 60 - 120 | 25-50 | 0.3 - 0.6 |
| A few susceptible crops may respond | 20 - 40 | 120-200 | 50 - 100 | 0.6 - 1.0 |
| No crop response | Above 40 | Above 200 | Above 100 | Above 1.0 |
| Levels are excessive and could cause problems | Above 150 | Above 2000 | Above 1000 | Above 3.0 |
| | | | | |

Adapted from H. M. Reisenauer (ed.), Soil and Plant Tissue Testing in California, University of California Division of Agricultural Science Bulletin 1879 (1978)

 $^{^1\}mathrm{Olsen}$ (0.5M, pH 8.5) sodium bicarbonate extractant $^2\mathrm{Exchangeable}$ with 1N ammonium acetate extractant

³ DTPA extractable Zn

TABLE 4.29. INTERPRETATION OF SOIL TEST RESULTS OBTAINED BY THE MEHLICH-1 DOUBLE ACID (0.05N HCl, 0.025N H₂SO₄) AND MEHLICH-3 SOIL EXTRACTANTS

Soil Amount (lb/acre)

| n (Ca) Mehlich-3 | 0-615 616-1,007 1,008-1,400 1,401-1,790 1,791+ |
|---------------------------------------|--|
| Calcium (Ca) Mehlich-1 Mehl | $0-400 \\ 401-800 \\ 801-1,200 \\ 1,201-1,600 \\ 296+$ |
| Magnesium (Mg) Mehlich-1 Mehlich-3 | 0-45 $46-83$ $84-143$ $144-295$ $1,601+$ |
| Magnesi Mehlich-1 | 0-35 36-70 71-125 126-265 266+ |
| Potassium (K) lich-1 Mehlich-3 | 0–40 41–81 82–145 146–277 278+ |
| Potassium (K) Mehlich-1 Mehlich-3 | $0-29 \\ 30-70 \\ 71-134 \\ 135-267 \\ 268+$ |
| Phosphorus (P) hlich-1 Mehlich-3 | 0-24 25-45 46-71 72-137 138+ |
| Phosphorus (P) Mehlich-1 Mehlich-3 | 0-13 14-27 28-45 46-89 90+ |
| Relative Level in Soil | Very low Low Medium High Very high |

Adapted from Commercial Vegetable Production Recommendations, Delaware Cooperative Extension Service Bulletin 137 (2005).

TABLE 4.30. INTERPRETATION OF THE MEHLICH-1 (DOUBLE-ACID) EXTRACTANT USED BY THE UNIVERSITY OF FLORIDA

| | | | ppm (soil) | | |
|--------------|--|-----------------------|-------------------------|------------------------|-------------|
| Element | Very Low | Low | Medium | High | Very High |
| P K Mg | <10 <20 | 10–15 20–35 <15 | 16–30 36–60 15–30 | 31–60 61–125 >30 | >60 >125 |
| | | Micro | nutrients | | |
| | | | Soil p | H (mineral soi | ls only) |
| | | | 5.5–5.9 | 6.0–6.4 ppm (soil) | 6.5–7.0 |
| | below which the response to a | | 0.1-0.3 | 0.3-0.5 | 0.5 |
| Test level a | above which co | pper | 2.0 – 3.0 | 3.0 - 5.0 | 5.0 |
| Test level l | may occur below which the presponse to a | | 3.0-5.0 | 5.0-7.0 | 7.0-9.0 |
| Test level | below which the response to a | | 0.5 | 0.5–1.0 | 1.0-3.0 |

Adapted from G. Hochmuth and E. Hanlon, "IFAS Standardized Fertilization Recommendations for Vegetable Crops" (Florida Cooperative Extension Service Circular 1152, 2000), http://edis.ifas.ufl.edu/CV002.

TABLE 4.31. GUIDE FOR DIAGNOSING NUTRIENT STATUS OF CALIFORNIA SOILS FOR VEGETABLE CROPS¹

Vegetable Yield Response to Fertilizer Application

| Vegetable | $Nutrient^1$ | Likely (soil ppm less than) | Not Likely (soil ppm more than) |
|---------------------------|------------------------|--------------------------------|------------------------------------|
| Lettuce | P | 15 | 25 |
| | K | 50 | 80 |
| | $\mathbf{Z}\mathbf{n}$ | 0.5 | 1.0 |
| Cantaloupe | P | 8 | 12 |
| • | K | 80 | 100 |
| | $\mathbf{Z}\mathbf{n}$ | 0.4 | 0.6 |
| Onion | P | 8 | 12 |
| | K | 80 | 100 |
| | $\mathbf{Z}\mathbf{n}$ | 0.5 | 1.0 |
| Potato (mineral | P | 12 | 25 |
| soils) | K | 100 | 150 |
| | Zn | 0.3 | 0.7 |
| Tomato | P | 8 | 12 |
| | K | 100 | 150 |
| | $\mathbf{Z}\mathbf{n}$ | 0.3 | 0.7 |
| Warm-season vegetables | P | 8 | 12 |
| | K | 50 | 70 |
| | $\mathbf{Z}\mathbf{n}$ | 0.2 | 0.5 |
| Cool-season vegetables | P | 20 | 30 |
| - | K | 50 | 80 |
| | $\mathbf{Z}\mathbf{n}$ | 0.5 | 1.0 |

Adapted from Soil and Plant Tissue Testing in California, University of California Division Agricultural Science Bulletin 1879 (1983). Updated 1996, personal communication, T. K. Hartz, University of California—Davis.

PO₄-P: 0.5M pH 8.5 sodium bicarbonate (NaHCO₃)

K: 1.0M ammonium acetate (NH₄OAc)

Zn: 0.005M diethyienetriaminepentaacetic acid (DTPA)

¹Soil extracts:

PRE-SIDEDRESS NITROGEN TEST FOR SWEET CORN

The Pre-sidedress Nitrate Test was developed to aid farmers in the prediction of nitrogen needs by corn at the time when sidedress applications are normally made. This test takes into consideration nitrogen released from organic nutrient sources (such as manure, compost, cover crops, and soil organic matter) in addition to nitrogen fertilizer.

Sampling Procedure for Nitrogen Soil Test

- 1. Sample soil when corn is 8-12 in. tall.
- 2. Collect 15–20 soil cores per field to a depth of 12 in., if possible. If not, sample as deeply as possible. Avoid areas where starter fertilizer bands were applied, areas where manure was stacked, and areas where starter fertilizer applications were unusually heavy or light.
- 3. Combine the cores for each field and mix completely. Take a subsample of approximately 1 cup and dry it immediately. Soil can be dried in an oven at about 200°F. Samples can also be air dried if spread out thinly on a nonabsorbent material in a dry, well-ventilated area. A fan reduces drying time. Do not put wet samples on absorbent material because it will absorb some nitrate. The longer the delay in drying the sample, the less accurate the results will be.

TABLE 4.32. SWEET CORN NITROGEN TEST

| $\begin{array}{c} \text{Soil Test Results} \\ \text{(ppm NO}_3\text{N)} \end{array}$ | Recommended Nitrogen Sidedressing (lbs actual N/acre) |
|--|---|
| 0–10 | 130 |
| 11-20 $21-25$ | 100 50 |
| 25+ | 0 |

Adapted from Vern Grubinger, University of Vermont Cooperative Extension Service, http://www.uvm.edu/vtvegandberry/factsheets/PSNT.html. Similar research results were obtained with pumpkin by T. F. Morris et al. (University of Connecticut, 1999), http://www.hort.uconn.edu/ipm/veg/htms/presidrs.htm.

Additional references for soil testing for vegetable fertilizer recommendations:

- E. A. Hanlon, Procedures Used by State Soil Testing Laboratories in the Southern Region of the United States, (Southern Cooperative Series Bulletin 190-B, 1998), http://www.imok.ufl.edu/hanlon/bull190.pdf.
- H. M. Reisenauer, J. Quick, R. E. Voss, and A. L. Brown, *Chemical Soil Tests for Soil Fertility Evaluation* (University of California Vegetable Research and Information Center), http://vric.ucdavis.edu.

TABLE 4.33. CONVERSION OF FERTILIZER RATES FROM APPLICATION ON A PER-ACRE BASIS TO RATES BASED ON LINEAR BED FEET FOR FULL-BED MULCHED CROPS

Typical bed spacing for mulched vegetables grown in Florida:

Rows of Plants

| Vegetable | $\begin{array}{c} \text{Typical Spacing} \\ \text{(ft)}^1 \end{array}$ | Rows of Plants per Bed | Vegetable | Typical Spacing (ft) | Rows of Plants per Bed |
|-------------|--|---------------------------|---------------|----------------------|---------------------------|
| Broccoli | 9 | 23 | Lettuce | 4 | 23 |
| Cabbage | 9 | 2 | Pepper | 9 | 2 |
| Cantalonbe | 5 | 1 | Summer squash | 9 | 2 |
| Cauliflower | 9 | 2 | Strawberry | 4 | 2 |
| Cucumber | 9 | 2 | Tomato | 9 | 1 |
| Eggplant | 9 | 1 | Watermelon | œ | 1 |
| | 10. | - | | | |

| | 180 | | 1.24 | 1.65 | 2.07 | 2.48 | 3.31 |
|--|---------------------|---|------|------|------|------|------|
| | 160 | | 1.10 | 1.47 | 1.84 | 2.20 | 2.94 |
| (Jb/A) | 140 | 100 LBF) | 96.0 | 1.29 | 1.61 | 1.93 | 2.57 |
| O_5 , or K_2O) (| 120 | or K_2O) (lb/ | 0.83 | 1.10 | 1.38 | 1.65 | 2.20 |
| Recommended Fertilizer (N, P ₂ O ₅ , or K ₂ O) (lb/A) | 100 | te (N, $\mathrm{P_2O_5}$, | 0.69 | 0.92 | 1.15 | 1.38 | 1.84 |
| | 80 | Resulting Fertilizer Rate (N, P_2O_6 , or K_2O) (lb/100 LBF) | 0.55 | 0.73 | 0.92 | 1.10 | 1.47 |
| Recom | 09 | Resulting 1 | 0.41 | 0.55 | 0.69 | 0.83 | 1.10 |
| | 40 | | 0.28 | 0.37 | 0.46 | 0.55 | 0.73 |
| | 20 | | 0.14 | 0.18 | 0.23 | 0.28 | 0.37 |
| Tvnical | Bed Spacing (ft) | | က | 4 | 5 | 9 | 80 |

To determine the correct fertilization rate in 1b nutrient per 100 linear bed feet (LBF), choose the crop and its typical bed spacing, Locate that typical bed spacing value in the bottom part of the table. Then locate the desired value for recommended fertilizer rate. Read down the column under recommended fertilizer rate until you reach the value in the row for your typical bed spacing. Adapted from G. J. Hoehmuth, "Soil and Fertilizer Management for Vegetable Production in Florida," in D. N. Maynard and G. J. Hoehmuth (eds.), Vegetable Production Guide for Florida (Florida Cooperative Extension Service Circular SP-170, 1995), 2-17.

(DELAWARE, MARYLAND, NEW JERSEY, PENNSYLVANIA, AND VIRGINIA) STATES BASED TABLE 4.34. RATES OF FERTILIZERS RECOMMENDED FOR VEGETABLE CROPS IN MID-ATLANTIC ON SOIL ANALYSES¹

| | | Ą | Amount P_2O_5 (lb/acre) | /acre) | • | Amount K ₂ O (lb/acre) | /acre) |
|--------------------------|-----------------------|---------------|---------------------------|-------------------|---------------|-----------------------------------|-------------------|
| Vegetable | Amount N (lb/acre) | Low Soil P | Medium Soil P | Optimum Soil P | Low Soil K | Medium Soil K | Optimum Soil K |
| Asparagus (cutting beds) | 50 | 200 | 100 | 50 | 200 | 100 | 50 |
| Bean, snap | 40-80 | 80 | 09 | 40 | 80 | 09 | 40 |
| Beet | 75-100 | 150 | 100 | 20 | 150 | 100 | 20 |
| Broccoli | 150 - 200 | 200 | 100 | 20 | 200 | 100 | 20 |
| Cabbage | 100 - 150 | 200 | 100 | 20 | 200 | 100 | 20 |
| Cantaloupe | 75-100 | 150 | 100 | 20 | 200 | 150 | 100 |
| Carrot | 50 - 80 | 150 | 100 | 20 | 150 | 100 | 20 |
| Cauliflower | 100 - 150 | 200 | 100 | 20 | 200 | 100 | 20 |
| Celery | 150 - 175 | 250 | 150 | 100 | 250 | 150 | 100 |
| Cucumber | 100 - 125 | 150 | 100 | 20 | 200 | 150 | 100 |
| Eggplant | 125 - 150 | 250 | 150 | 100 | 250 | 150 | 100 |
| Lettuce, iceberg | 08 - 09 | 200 | 150 | 100 | 200 | 150 | 100 |
| Leek | 100 - 125 | 200 | 150 | 100 | 200 | 150 | 100 |
| Onion, bulbs | 75 - 100 | 200 | 100 | 50 | 200 | 100 | 20 |

(DELAWARE, MARYLAND, NEW JERSEY, PENNSYLVANIA, AND VIRGINIA) STATES BASED TABLE 4.34. RATES OF FERTILIZERS RECOMMENDED FOR VEGETABLE CROPS IN MID-ATLANTIC ON SOIL ANALYSES¹ (Continued)

| | | Ą | Amount P_2O_5 (lb/acre) | /acre) | | Amount K ₂ O (lb/acre) | /acre) |
|--------------------|-----------------------|---------------|---------------------------|-------------------|---------------|-----------------------------------|-------------------|
| Vegetable | Amount N (lb/acre) | Low Soil P | Medium Soil P | Optimum Soil P | Low Soil K | Medium Soil K | Optimum Soil K |
| Pea | 40–80 | 120 | 80 | 40 | 120 | 80 | 40 |
| Pepper | 100 - 130 | 200 | 150 | 100 | 200 | 150 | 100 |
| Potato | 125 - 150 | 200 | 150 | 100 | 300 | 200 | 100 |
| Pumpkin | 50 - 100 | 150 | 100 | 20 | 200 | 150 | 100 |
| Spinach | 100 - 195 | 200 | 150 | 100 | 200 | 150 | 100 |
| Squash, summer | 75 - 100 | 150 | 100 | 20 | 200 | 150 | 100 |
| Strawberry | 60 - 110 | 165 | 115 | 65 | 165 | 115 | 65 |
| (established) | | | | | | | |
| Sweet corn (fresh) | 125 - 150 | 160 | 120 | 80 | 160 | 120 | 80 |
| Sweet potato | 50 - 75 | 200 | 100 | 20 | 300 | 200 | 100 |
| Tomato (fresh) | 80 - 90 | 200 | 150 | 100 | 300 | 200 | 100 |
| Watermelon | 125 - 150 | 150 | 100 | 50 | 200 | 150 | 100 |
| | | | | | | | |

Adapted from Commercial Vegetable Production Recommendations, Delaware Cooperative Extension Service Bulletin 137 (2005).

¹A common recommendation is to broadcast and work deeply into the soil one-third to one-half of the fertilizer at planting and to apply the balance as a side dressing in one or two applications after the crop is fully established.

TABLE 4.35. RATES OF FERTILIZERS RECOMMENDED FOR VEGETABLE CROPS IN FLORIDA ON SANDY SOILS BASED ON MEHLICH-I SOIL TEST RESULTS

| | | $\mathrm{P_2O_5}$ (lb | $\mathrm{P_2O_5}(\mathrm{lb/acre})^1$ Soil-test P | -test P | $ m K_2O~(lb$ | $ m K_2O~(lb/acre)^1~Soil-test~K$ | -test K |
|-----------------|-------------|-----------------------|---|---------|---------------|-----------------------------------|---------|
| Vegetable | N (lb/acre) | Very Low | Low | Medium | Very Low | Low | Medium |
| Bean | 100 | 120 | 100 | 80 | 120 | 100 | 80 |
| Beet | 120 | 120 | 100 | 80 | 120 | 100 | 80 |
| Broccoli | 175 | 150 | 120 | 100 | 150 | 120 | 100 |
| Cabbage | 175 | 150 | 120 | 80 | 150 | 120 | 80 |
| Cantalonbe | 150 | 150 | 120 | 80 | 150 | 120 | 80 |
| Carrot | 175 | 150 | 120 | 100 | 150 | 120 | 100 |
| Cauliflower | 175 | 150 | 120 | 100 | 150 | 120 | 100 |
| Celery | 200 | 200 | 150 | 100 | 250 | 150 | 100 |
| Chinese cabbage | 150 | 150 | 120 | 80 | 150 | 120 | 80 |
| Collards | 150 | 150 | 120 | 80 | 150 | 120 | 80 |
| Cucumber | 150 | 120 | 100 | 80 | 120 | 100 | 80 |
| Eggplant | 200 | 150 | 120 | 100 | 160 | 130 | 100 |
| Lettuce | 200 | 150 | 120 | 80 | 150 | 120 | 80 |
| Mustard | 120 | 150 | 120 | 100 | 150 | 120 | 100 |
| Okra | 120 | 150 | 120 | 100 | 150 | 120 | 100 |
| Onion | 150 | 150 | 120 | 80 | 150 | 120 | 80 |

Medium 140 80 80 80 80 80 80 80 80 K₂O (lb/acre)¹ Soil-test K RATES OF FERTILIZERS RECOMMENDED FOR VEGETABLE CROPS IN FLORIDA ON Low 100 100 100 SANDY SOILS BASED ON MEHLICH-I SOIL TEST RESULTS (Continued) Very Low 120 150 Medium P_2O_5 (lb/acre)¹ Soil-test P Low 120 120 Very Low N (lb/acre) 90 150 150 **TABLE 4.35.** Pea, southern Vegetable Strawberry Squash Spinach Parsley Pepper Potato Radish

Adapted from G. Hochmuth and E. Hanlon, "IFAS Standardized Fertilization Recommendations for Vegetable Crops," Florida Cooperative Extension Service Circular 1152 (2000), http://edis.ifas.ufl.edu/CV002.

> Sweet potato Watermelon

Tomato

Sweet corn

No P or K recommended for soils testing high except for potato, which receives no P but receives 140 lb K₂O/acre.

TABLE 4.36. FERTILIZATION RECOMMENDATIONS FOR NEW ENGLAND VEGETABLES

| | | | δ. | Soil Phosphorus | rus | | | 01 | Soil Potassium | ш | |
|----------------------|-----------------|-------------|------------|-----------------------|------|--------------|-------------|-------------------|---------------------|-----------|--------------|
| Crop | Nitrogen | Very Low | Low | Medium | High | Very High | Very Low | Low | Medium | High | Very High |
| | (lb/acre) | | | $ m P_2O_5$ (lb/acre) | e) | | | | $ m K_2O~(lb/acre)$ | (е | |
| Asparagus, | 75 | 200 | 175 | 150 | 100 | 50 | 300 | 250 | 200 | 150 | 75 |
| Bean | 20 | 100 | 75 | 20 | 25 | 25 | 100 | 75 | 20 | 50 | 25 |
| Beet, Swiss chard | 100-130 | 150 | 125 | 100 | 20 | 0 | 300 | 200 | 100 | 20 | 25 |
| Carrot, Parsnip | 110-150 | 150 | 100 | 75 | 20 | 0 | 400 | 350 | 250 | 150 | 0 - 75 |
| Cantaloupe Celerv | 130 180 | 150 200 | 120 150 | 100 100 | 20 | 0 0 | 200 300 | $\frac{150}{240}$ | 100 180 | 80 120 | 0-0 |
| Cole crops | 160 | 200 | 170 | 130 | 100 | 20 | 175 | 150 | 125 | 20 | 0 |
| Sweet Corn, | 100-130 | 110 | 80 | 40 | 20 | 0 | 200 | 160 | 130 | 30 | 0 |
| Sweet Corn, | 100–160 | 110 | 80 | 40 | 20 | 0 | 200 | 160 | 130 | 30 | 0 |
| Cucumber Eggplant | $130 \\ 80-110$ | 150 200 | 120 | 100 | 80 | 0 0 | 200 | 150 150 | 100 | 80 | 0 0 |
| Gourd | 06 | 125 | 100 | 75 | 20 | 0 | 150 | 125 | 100 | 75 | 0 |

TABLE 4.36. FERTILIZATION RECOMMENDATIONS FOR NEW ENGLAND VEGETABLES (Continued)

| | Very High | | 0 | 0 | 0 | 0 | 150 | 0 | 25 | 0 | 0 | 0 | 0 |
|-----------------|--------------|----------------------------|---------------------|-------|-----|--------|-----------|----------|------------------|---------------------|----------|-----------|------------|
| m | High | (6 | 06 | 50 | 20 | 20 | 180 | 70 | 50 | 25 | 20 | 100 | 80 |
| Soil Potassium | Medium | K ₂ O (lb/acre) | 140 | 100 | 75 | 100 | 200 | 100 | 75 | 50 | 100 | 150 | 100 |
| 01 | Low | | 165 | 150 | 100 | 150 | 225 | 150 | 100 | 75 | 150 | 200 | 150 |
| | Very Low | | 190 | 175 | 150 | 200 | 250 | 200 | 125 | 100 | 200 | 250 | 200 |
| | Very High | | 0 | 0 | 25 | 0 | 150 | 0 | 0 - 25 | 0 | 30 | 0 | 0 |
| sn. | High | (e | 06 | 20 | 20 | 20 | 180 | 0-20 | 50 | 25 | 09 | 20 | 80 |
| Soil Phosphorus | Medium | $ m P_2O_5$ (lb/acre) | 140 | 100 | 75 | 100 | 200 | 100 | 75 | 50 | 100 | 100 | 100 |
| Q | Low | | 165 | 150 | 100 | 150 | 250 | 125 | 100 | 75 | 120 | 150 | 120 |
| | Very Low | | 190 | 175 | 150 | 200 | 300 | 150 | 125 | 100 | 150 | 200 | 150 |
| | Nitrogen | (lb/acre) | 80–125 | 130 | 75 | 140 | 120 - 180 | 70–90 | 20 | 50 | 90 - 110 | 140 - 160 | 130 |
| | Crop | | Lettuce, Endive, | Onion | Pea | Pepper | Potato | Pumpkin, | Squasn Radish | Rutabaga, Turnip | Spinach | Tomato | Watermelon |

Adapted from J.C. Howell (ed.), New England Vegetable Management Guide (Cooperative Extension Services of New England States, 2004–2005).

TABLE 4.37. FERTILIZER RATES RECOMMENDED FOR VEGETABLE CROPS IN NEW YORK

Amount (lb/acre)1 Vegetable Ν K₂O P_2O_5 50 25 - 7540-80 Asparagus Bean 40 40 - 8020 - 60Beet 150 - 17550 - 150100-300 Broccoli 100 - 12040 - 12060 - 160Brussels sprouts 100 - 12040 - 12060 - 160Cabbage 100 - 12040 - 12060 - 160Carrot 80-90 40 - 12060 - 160Cantaloupe 100 - 12040 - 12040 - 120Cauliflower 100 - 12040 - 12060 - 160Celerv 130 - 15050 - 150120 - 240Cucumber 100 - 12040 - 12040 - 120Eggplant 120 60 - 15060 - 150Endive 100 30 - 12050 - 150Lettuce 100 30 - 12050 - 150Onion (mineral soil) 90 - 12050 - 15050 - 150Pea 40 - 5050 - 10040 - 120Pepper 125 75 - 15075 - 150Potato 120 - 175120 - 24075 - 240Pumpkin 100 - 12040 - 12040 - 120Radish 50 50 - 11050 - 150Spinach 100 - 12580 - 14050 - 150Squash, summer 100 - 12040 - 12040 - 120Squash, winter 100 - 12040 - 12040 - 120

 $\label{lem:commercial} A dapted from S. \ Reiners \ and \ C. \ Petzuldt \ (eds.), \ \textit{Integrated Crop and Pest Management Guidelines for Commercial Vegetable Production} \ (Cornell \ Cooperative \ Extension \ Service, 2005), \ http://www.nysaes.cornell.edu/recommends/.$

120 - 140

100

100 - 120

50

40 - 120

60 - 150

50 - 110

40 - 120

40 - 120

60 - 150

50 - 150

40 - 120

Sweet corn

Watermelon

Tomato

Turnip

¹Total amounts are listed; application may be broadcast and plow down, broadcast and disk in, band, or sidedress. Actual rate of fertilization depends on soil type, previous cropping history, and soil test results. Ranges reflect recommendations made for high to low soil test situations. See above document for details.

ADDITIONAL VEGETABLE PRODUCTION GUIDES CONTAINING FERTILIZER RECOMMENDATIONS

- New England Vegetable Management Guide, http://www.nevegetable.org
 Oregon Vegetable Production Guides, http://oregonstate.edu/Dept/NWREC/
 vegindex.html
- Texas Vegetable Grower's Handbook, http://aggie-horticulture.tamu.edu/extension/veghandbook/index.html
- Ohio Vegetable Production Guide, http://ohioline.osu.edu/b672/index.html
 Cornell (New York) Integrated Crop and Pest Management Guidelines for
 Commercial Vegetable Production, http://www.nysaes.cornell.edu/
 recommends/

13 NUTRIENT DEFICIENCIES

TABLE 4.38. A KEY TO NUTRIENT DEFICIENCY SYMPTOMS

| Nutrient | Plant Symptoms | Occurrence |
|-----------------|---|--|
| Primary | | |
| Nitrogen | Stems are thin, erect, and hard. Leaves are smaller than normal, pale green or yellow; lower leaves are affected first, but all leaves may be deficient in severe cases. Plants grow slowly. | Excessive leaching on light soils |
| Phosphorus | Stems are thin and shortened. Leaves develop purple coloration, first on undersides and later throughout. Plants grow slowly, and maturity is delayed. | On acid soils; temporary deficiencies on cold, wet soils |
| Potassium | Older leaves develop gray or tan areas near the margins. Eventually a scorch around the entire leaf margin may occur. Chlorotic areas may develop throughout leaf. | Excessive leaching on light soils |
| Secondary Nutri | ents and Micronutrients | |
| Boron | Growing points die; stems are shortened and hard; leaves are distorted. Specific deficiencies include browning of cauliflower, cracked stem of celery, blackheart of beet, and internal browning of turnip. | On soils with a pH above 6.8 or on crops with a high boron requirement |

TABLE 4.38. A KEY TO NUTRIENT-DEFICIENCY SYMPTOMS (Continued)

| Nutrient | Plant Symptoms | Occurrence |
|-----------|--|---|
| Calcium | Stem elongation restricted by death of the growing point. Root tips die, and root growth is restricted. Specific deficiencies include blossom-end rot of tomato, brownheart of escarole, celery blackheart, and carrot cavity spot. | On acid soils, following leaching rains, on soils with very high potassium levels, or on very dry soils |
| Copper | Yellowing of leaves. Leaves may become elongated. Onion bulbs are soft, with thin, pale-yellow scales. | Most cases of copper deficiency occur on muck or peat soils. |
| Iron | Distinct yellow or white areas appear between the veins on the youngest leaves. | On soils with a pH above 6.8 |
| Magnesium | Initially, older leaves show yellowing between the veins; continued deficiency causes younger leaves to become affected. Older leaves may fall with prolonged deficiency. | On acid soils, on soils with very high potassium levels, or on very light soils subject to leaching |
| Manganese | Yellow mottled areas, not as intense as with iron deficiency, appear on the youngest leaves. This finally results in an overall pale appearance. In beet, foliage becomes densely red. Onion and corn show narrow striping of yellow. | On soils with a pH above 6.7 |

TABLE 4.38. A KEY TO NUTRIENT-DEFICIENCY SYMPTOMS (Continued)

| Nutrient | Plant Symptoms | Occurrence |
|------------|--|--|
| Molybdenum | Pale, distorted, very narrow leaves with some interveinal yellowing on older leaves. Whiptail of cauliflower; small, open, loose curds | On very acid soils |
| Zinc | Small reddish-brown spots on cotyledon leaves of bean. Green and yellow broad striping at base of leaves of corn. Interveinal yellowing with marginal burning on beet. | On wet soils in early spring; often related to heavy phosphorus fertilization |

14 MICRONUTRIENTS

TABLE 4.39. INTERPRETATION OF MICRONUTRIENT SOIL TESTS

| Element | ${f Method}$ | Range in Critical Level (ppm) ¹ |
|-----------------|---|--|
| Boron (B) | Hot H ₂ O | 0.1-0.7 |
| Copper (Cu) | $NH_4C_9H_3O_9$ (pH 4.8) | 0.2 |
| copper (cu) | 0.5M EDTA | 0.1-0.7 |
| | 0.43N HNO ₃ | 3–4 |
| | Biological assay | 2–3 |
| Iron (Fe) | $NH_4C_9H_3O_9$ (pH 4.8) | 2 |
| , , | $DTPA + CaCl_2 (pH 7.3)$ | 2.5 - 4.5 |
| Manganese (Mn) | $0.05N \text{ HCl} + 0.025N \text{ H}_2\text{SO}_4$ | 5–9 |
| - | $0.1N \text{ H}_3\text{PO}_4$ and $3N \text{ NH}_4\text{H}_2\text{PO}_4$ | 15-20 |
| | Hydroquinone + NH ₄ C ₂ H ₃ O ₂ | 25-65 |
| | $ m H_2O$ | 2 |
| Molybdenum (Mo) | $(NH_4)_2C_2O_4$ (pH 3.3) | 0.04 - 0.2 |
| Zinc (Zn) | 0.1 <i>N</i> HCl | 1.0 - 7.5 |
| | Dithizone + $NH_4C_2H_3O_2$ | 0.3 - 2.3 |
| | $EDTA + (NH_4)_2CO_3$ | 1.4 - 3.0 |
| | $DTPA + CaCl_2 (pH 7.3)$ | 0.5 - 1.0 |
| | | |

Reprinted with permission from S. S. Mortvedt, P. M. Giordano, and W. L. Lindsay (eds.), *Micronutrients in Agriculture* (Madison, Wis.: Soil Science Society of America, 1972).

 $^{^1}$ Deficiencies are likely to occur when concentrations are below the critical level. Consult the state's Extension Service for the latest interpretations.

TABLE 4.40. MANGANESE RECOMMENDATIONS FOR RESPONSIVE CROPS GROWN ON MINERAL SOILS IN MICHIGAN

| | | | | Soil pH | | | |
|-------------------------------|-----|-----|---------|----------|-----------|-----|-----|
| Soil Test ppm ¹ | 5.8 | 6.0 | 6.2 | 6.4 | 6.6 | 6.8 | 7.0 |
| | | | Band-ar | plied Mn | (lb/acre) | | |
| 2 | 2 | 4 | 5 | 7 | 9 | 10 | 12 |
| 4 | 1 | 2 | 3 | 5 | 6 | 7 | 8 |
| 8 | 0 | 1 | 2 | 3 | 5 | 6 | 7 |
| 12 | 0 | 0 | 1 | 2 | 3 | 4 | 6 |
| 16 | 0 | 0 | 0 | 1 | 2 | 3 | 4 |
| 20 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

Adapted from D. D. Warncke, D. R. Christenson, L. W. Jacobs, M. L. Vitosh, and B. H. Zandstra, Fertilizer Recommendations for Vegetable Crops in Michigan (Michigan Cooperative Extension Service Bulletin E550B, 1994), http://web1.msue.msu.edu/msue/imp/modaf/55092001.html.

 $^{^{1}}$ 0.1N HCl extractant

TABLE 4.41. MANGANESE RECOMMENDATIONS FOR RESPONSIVE CROPS GROWN ON ORGANIC SOILS IN MICHIGAN

| | | | | Soil pH | | | | |
|-------------------------------|---------------------------|-----|-----|---------|------|-----|-----|--|
| Soil Test ppm ¹ | 5.8 | 6.0 | 6.2 | 6.4 | 6.6 | 6.8 | 7.0 | |
| | Band-applied Mn (lb/acre) | | | | | | | |
| 2 | 2 | 4 | 5 | 7 | 9 | 10 | 12 | |
| 4 | 1 | 3 | 5 | 6 | 8 | 10 | 11 | |
| 8 | 0 | 1 | 3 | 5 | 7 | 8 | 10 | |
| 12 | 0 | 0 | 2 | 4 | 6 | 7 | 9 | |
| 16 | 0 | 0 | 1 | 3 | 4 | 6 | 8 | |
| 20 | 0 | 0 | 0 | 1 | 3 | 5 | 6 | |
| 24 | 0 | 0 | 0 | 0 | 2 | 4 | 5 | |
| 28 | 0 | 0 | 0 | 0 | 1 | 2 | 4 | |
| 32 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | |

Adapted from D. D. Warncke, D. R. Christenson, L. W. Jacobs, M. L. Vitosh, and B. H. Zandstra, Fertilizer Recommendations for Vegetable Crops in Michigan (Michigan Cooperative Extension Service Bulletin E550B, 1994).

 $^{^{1}}$ 0.1N HCl extractant

TABLE 4.42. ZINC RECOMMENDATIONS FOR RESPONSIVE CROPS GROWN ON MINERAL AND ORGANIC SOILS IN MICHIGAN

| | | Soil | pH | |
|-------------------------------|-----|--------------|---------------------------|-----|
| Soil Test ppm ¹ | 6.7 | 7.0 | 7.3 | 7.6 |
| | | Band-applied | Zn (lb/acre) ² | |
| 2 | 1 | 2 | 4 | 5 |
| 4 | 0 | 1 | 3 | 4 |
| 6 | 0 | 0 | 2 | 4 |
| 8 | 0 | 0 | 1 | 3 |
| 10 | 0 | 0 | 0 | 2 |
| 12 | 0 | 0 | 0 | 1 |

Adapted from D. D. Warncke, D. R. Christenson, L. W. Jacobs, M. L. Vitosh, and B. H. Zandstra, Fertilizer Recommendations for Vegetable Crops in Michigan (Michigan Cooperative Extension Service Bulletin E550B, 1994).

^{10.1}N HCl extractant

 $^{^{2}\,\}mathrm{Rates}$ may be divided by 5 when chelates are used.

TABLE 4.43. COPPER RECOMMENDATIONS FOR CROPS GROWN ON ORGANIC SOILS IN MICHIGAN

| | Crop Response | | | |
|-------------------------------|---------------|--------------|----------|--|
| Soil Test ppm ¹ | Low | Medium | High | |
| | | Cu (lb/acre) | | |
| 1 | 3 | 4 | 6 | |
| 4 | 3 | 4 | 5 | |
| 8 | 2 | 3 | 4 | |
| 12 | 1 | 2 | 3 | |
| 16 | 1 | 2 | 2 | |
| 20 | 1 | 1 | 2 | |
| 24 | 0 | 1 | 1 | |

Adapted from D. D. Warncke, D. R. Christenson, L. W. Jacobs, M. L. Vitosh, and B. H. Zandstra, Fertilizer Recommendations for Vegetable Crops in Michigan (Michigan Cooperative Extension Service Bulletin E550B, 1994), http://web1.msue.msu.edu/msue/imp/modaf/55092001.html.

 $^{^{1}\,0.1}N$ HCl extractant

TABLE 4.44. RELATIVE RESPONSE OF VEGETABLES TO MICRONUTRIENTS¹

Response to Micronutrient

| Vegetable | Manganese | Boron | Copper | Zinc | Molybdenum | Iron |
|-------------|-----------|--------|--------|--------|------------|-----------------------|
| | , | , | , | , | , | ; |
| Asparagus | Low | Low | Low | Low | Low | Medium |
| Bean | High | Low | Low | High | Medium | High |
| Beet | High | High | High | Medium | High | High |
| Broccoli | Medium | High | Medium | I | High | High |
| Cabbage | Medium | Medium | Medium | Low | Medium | Medium |
| Carrot | Medium | Medium | Medium | Low | Low | l |
| Cauliflower | Medium | High | Medium | I | High | High |
| Celery | Medium | High | Medium | I | Low | I |
| Cucumber | High | Low | Medium | I | I | I |
| Lettuce | High | Medium | High | Medium | High | l |
| Onion | High | Low | High | High | High | I |
| Pea | High | Low | Low | Low | Medium | I |
| Potato | High | Low | Low | Medium | Low | I |
| Radish | High | Medium | Medium | Medium | Medium | I |
| Spinach | High | Medium | High | High | High | High |
| Sweet corn | High | Medium | Medium | High | Low | Medium |
| Tomato | Medium | Medium | High | Medium | Medium | High |
| Turnip | Medium | High | Medium | ļ | Medium | I |

Adapted from M. L. Vitosh, D. D. Warncke, and R. E. Lucas, Secondary and Micronutrients for Vegetables and Field Crops (Michigan Extension Bulletin E-486, 1994), http://web1.msue.msu.edu/msue/imp/modf1/05209701.html.

¹The crops listed respond as indicated to applications of the respective micronutrient when that micronutrient concentration in the soil is low.

TABLE 4.45. BORON REQUIREMENTS OF VEGETABLES ARRANGED IN APPROXIMATE ORDER OF DECREASING REQUIREMENTS

| High Requirement (more than 0.5 ppm in soil) | Medium Requirement (0.1– 0.5 ppm in soil) | Low Requirement (less than 0.1 ppm in soil) |
|--|---|---|
| Beet | Tomato | Corn |
| Turnip | Lettuce | Pea |
| Cabbage | Sweet potato | Bean |
| Broccoli | Carrot | Lima bean |
| Cauliflower | Onion | Potato |
| Asparagus | | |
| Radish | | |
| Brussels sprouts | | |
| Celery | | |
| Rutabaga | | |

Adapted from K. C. Berger, "Boron in Soils and Crops," Advances in Agronomy, vol. 1, (New York: Academic Press, 1949), 321–351.

TABLE 4.46. RELATIVE TOLERANCE OF VEGETABLES TO BORON, ARRANGED IN ORDER OF INCREASING SENSITIVITY

| Tolerant | Semitolerant | Sensitive |
|--|---|-----------------------------|
| Asparagus Artichoke Beet Cantaloupe Broad bean Onion Turnip Cabbage Lettuce Carrot | Celery Potato Tomato Radish Corn Pumpkin Bell pepper Sweet potato Lima bean | Jerusalem artichoke Bean |
| | | |

 $\label{eq:Adapted from L. V. Wilcox, Determining the Quality of Irrigation Water, USDA Agricultural Information Bulletin 197 (1958).$

TABLE 4.47. SOIL AND FOLIAR APPLICATION OF SECONDARY AND TRACE ELEMENTS

Vegetables differ in their requirements for these secondary nutrients. Availability in the soil is influenced by soil reaction and soil type. Use higher rates on muck and peat soils than on mineral soils and lower rates for band application than for broadcast. Foliar application is one means of correcting an evident deficiency that appears while the crop is growing.

| Element | Application Rate (per acre basis) | Source | Composition |
|-----------|-----------------------------------|---|-------------|
| Boron | 0.5–3.5 lb (soil) | Borax (Na ₂ B ₄ O ₇ · 10H ₂ O) | 11% B |
| | | Boric acid (H ₃ BO ₃) | 17% B |
| | | Sodium pentaborate $(Na_2B_{10}O_{16} \cdot 10H_2O)$ | 18% B |
| | | Sodium tetraborate $(Na_2B_4O_7)$ | 21% B |
| Calcium | 2-5 lb (foliar) | Calcium chloride (CaCl ₂) | 36% Ca |
| | | Calcium nitrate (CaNO ₃ · 2H ₂ O) | 20% Ca |
| | | Liming materials and gypsum supply calcium when used as soil amendments | |
| Copper | 2-6 lb (soil) | Cupric chloride (CuCl ₂) | 47% Cu |
| | | Copper sulfate ($CuSO_4 \cdot H_2O$) | 35% Cu |
| | | Copper sulfate (CuSO $_4$ · $_5$ H $_2$ O) | 25% Cu |
| | | Cupric oxide (CuO) | 80% Cu |
| | | Cuprous oxide (Cu ₂ O) | 89% Cu |
| | | Copper chelates | 8–13% Cu |
| Iron | 2–4 lb (soil) | Ferrous sulfate (FeSO $_4$ · 7H $_2$ O) | 20% Fe |
| | 0.5–1 lb (foliar) | Ferric sulfate [Fe ₂ (SO ₄) ₃ · 9H ₂ O] | 20% Fe |
| | | Ferrous carbonate (FeCO $_3$ · H_2 O) | 42% Fe |
| | | Iron chelates | 5–12% Fe |
| Magnesium | 25–30 lb (soil) | $\begin{array}{c} {\rm Magnesium~sulfate~(MgSO_4 \cdot } \\ {\rm 7H_2O)} \end{array}$ | 10% Mg |

TABLE 4.47. SOIL AND FOLIAR APPLICATION OF SECONDARY AND TRACE ELEMENTS (Continued)

| Element | Application Rate (per acre basis) | Source | Composition |
|------------|-----------------------------------|---|-------------|
| | 2–4 lb (foliar) | Magnesium oxide (MgO) | 55% Mg |
| | | Dolomitic limestone | 11% Mg |
| | | Magnesium chelates | 2-4% Mg |
| Manganese | 20–100 lb (soil) | Manganese sulfate (MnSO ₄ \cdot 3H ₂ O) | 27% Mn |
| | 2-5 lb (foliar) | Manganous oxide (MnO) | 41-68% Mn |
| | | Manganese chelates (Mn EDTA) | 12% Mn |
| Molybdenum | 25–400 g (soil) | Ammonium molybdate $[(NH_4)_6MO_7O_{24} \cdot 4H_2O]$ | 54% Mo |
| | 25 g (foliar) | Sodium molybdate (Na ₂ MoO ₄ · 2H ₂ O) | 39% Mo |
| Sulfur | 20-50 lb (soil) | Sulfur (S) | 100% S |
| | | Ammonium sulfate $[(NH_4)_2SO_4]$ | 24% S |
| | | Potassium sulfate (K ₂ SO ₄) | 18% S |
| | | Calcium sulfate (CaSO ₄) | 16-18% S |
| | | Ferric sulfate [Fe ₂ (SO ₄) ₃] | 18-19% S |
| Zinc | 2-10 lb (soil) | Zinc oxide (ZnO) | 80% Zn |
| | 0.25 lb (foliar) | Zinc sulfate ($ZnSO_4 \cdot 7H_2O$) | 23% Zn |
| | | Zinc chelates (Na ₂ Zn EDTA) | 14% Zn |

| ROPS | |
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| 5 | |
| NS BASED ON SOIL TESTS FOR VEGETABLE CROP? | |
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| TABLE 4.48. | |
| TABI | |

| Interpretat | Interpretation of Boron Soil Tests | Soil Tests | | Boron |
|-------------|------------------------------------|----------------|--|-----------------------------|
| mdd | lb/acre | Relative Level | R. Crops That Often Need Additional Boron | Recommendation (lb/acre) |
| 0.0 - 0.35 | 0.0-0.70 | Low | Beet, broccoli, Brussels sprouts, cabbage, cauliflower, celery, rutabaga, turnip | က |
| | | | Asparagus, carrot, eggplant, horseradish, leek, onion, parsnip, radish, squash, | 23 |
| | | | Strawberry, sweet corn, tomato Pepper, sweet potato | 1 |
| 0.36-0.70 | 0.36-0.70 0.71-1.40 | Medium | Beet, broccoli, Brussels sprouts, cabbage, cauliflower, celery, rutabaga, turnip | $1\frac{1}{2}$ |
| | | | Asparagus, carrot, eggplant, horseradish, leek, onion, parsnip, radish, squash, Strawberry, sweet corn, tomato | П |
| >0.70 | >1.40 | High | All crops | 0 |

Adapted from Commercial Vegetable Production Recommendations, Delaware Cooperative Extension Service Bulletin 137 (2005).

TABLE 4.49. TOLERANCE OF VEGETABLES TO A DEFICIENCY OF SOIL MAGNESIUM

| Tolerant | Not Tolerant |
|--------------|--------------|
| Bean | Cabbage |
| Beet | Cantaloupe |
| Chard | Corn |
| Lettuce | Cucumber |
| Pea | Eggplant |
| Radish | Pepper |
| Sweet potato | Potato |
| - | Pumpkin |
| | Rutabaga |
| | Tomato |
| | Watermelon |

Adapted from W. S. Ritchie and E. B. Holland, *Minerals in Nutrition*, Massachusetts Agricultural Experiment Station Bulletin 374 (1940).

15 FERTILIZER DISTRIBUTORS

ADJUSTMENT OF FERTILIZER DISTRIBUTORS

Each time a distributor is used, it is important to ensure that the proper quantity of fertilizer is being supplied. Fertilizers vary greatly in the way they flow through the equipment. Movement is influenced by the humidity of the atmosphere as well as the degree of granulation of the material.

TABLE 4.50. ADJUSTMENT OF ROW CROP DISTRIBUTOR

- Disconnect from one hopper the downspout or tube to the furrow opener for a row.
- 2. Attach a can just below the fertilizer hopper.
- 3. Fill the hopper under which the can is placed.
- 4. Engage the fertilizer attachment and drive the tractor the suggested distance according to the number of inches between rows.

| Distance Between Rows (in.) | Distance to Pull the Distributor (ft) |
|--------------------------------|--|
| 20 | 261 |
| 24 | 218 |
| 30 | 174 |
| 36 | 145 |
| 38 | 138 |
| 40 | 131 |
| 42 | 124 |
| | |

- 5. Weigh the fertilizer in the can. Each pound in it equals 100 lb/acre. Each tenth of a pound equals 10 lb/acre.
- Adjust the distributor for the rate of application desired, and then adjust the other distributor or distributors to the same setting.

TABLE 4.51. ADJUSTMENT OF GRAIN-DRILL-TYPE DISTRIBUTOR

- 1. Remove four downspouts or tubes.
- 2. Attach a paper bag to each of the four outlets.
- 3. Fill the part of the drill over the bagged outlets.
- 4. Engage the distributor and drive the tractor the suggested distance according to the inches between the drill rows.

| Distance to Pull the Drill (ft) |
|------------------------------------|
| 187 |
| 164 |
| 131 |
| 109 |
| 94 |
| |

5. Weigh total fertilizer in the four bags. Each pound equals 100 lb/acre. Each tenth of a pound equals 10 lb/acre.

TABLE 4.52. CALIBRATION OF FERTILIZER DRILLS

Set drill at opening estimated to give the desired rate of application. Mark level of fertilizer in the hopper. Operate the drill for 100 ft. Weigh a pail full of fertilizer. Refill hopper to marked level and again weigh pail. The difference is the pounds of fertilizer used in 100 ft. Consult the column under the row spacing being used. The left-hand column opposite the amount used shows the rate in pounds per acre at which the fertilizer has been applied. Adjust setting of the drill, if necessary, and recheck.

| Rate | Distance Between Rows (in.) | | | | |
|--------------------|-----------------------------|-------------------|-------------------|-------------------|-------------------|
| (lb/acre) | 18 | 20 | 24 | 36 | 48 |
| | Appro | oximate Amou | ınt of Fertilize | er (lb/100 ft of | f row) |
| | | | | | |
| 250 | 0.9 | 1.1 | 1.4 | 1.7 | 2.3 |
| 250 500 | 0.9 1.7 | 1.1 2.3 | 1.4 2.9 | 1.7 3.5 | |
| | | | | | 2.3 4.6 6.9 |
| 500 | 1.7 | 2.3 | 2.9 | 3.5 | 4.6 |
| 500 750 | 1.7 2.6 | $\frac{2.3}{3.4}$ | 2.9 4.3 | 3.5 5.2 | 4.6 6.9 |
| 500 750 1000 | 1.7 2.6 3.5 | 2.3 3.4 4.6 | 2.9 4.3 5.8 | 3.5 5.2 6.9 | 4.6 6.9 9.2 |

PART 6

VEGETABLE PESTS AND PROBLEMS

- 01 AIR POLLUTION
- 02 INTEGRATED PEST MANAGEMENT
- 03 SOIL SOLARIZATION
- 04 PESTICIDE USE PRECAUTIONS
- 05 PESTICIDE APPLICATION AND EQUIPMENT
- 06 VEGETABLE SEED TREATMENT
- 07 NEMATODES
- 08 DISEASES
- 09 INSECTS
- 10 PEST MANAGEMENT IN ORGANIC PRODUCTION SYSTEMS
- 11 WILDLIFE CONTROL

01 AIR POLLUTION

AIR POLLUTION DAMAGE TO VEGETABLE CROPS

Plant damage by pollutants depends on meteorological factors leading to air stagnation, the presence of a pollution source, and the susceptibility of the plants. Among the pollutants that affect vegetable crops are sulfur dioxide (SO_2) , ozone (O_3) , peroxyacetyl nitrate (PAN), chlorine (Cl_2) , and ammonia (NH_3) . The following symptoms are most likely to be observed on vegetables produced near heavily urbanized areas or industrialized areas, particularly where weather conditions frequently lead to air stagnation.

Sulfur dioxide: SO₂ causes acute and chronic plant injury. Acute injury is characterized by dead tissue between the veins or on leaf margins. The dead tissue may be bleached, ivory, tan, orange, red, reddish brown, or brown, depending on the plant species, time of year, and weather. Chronic injury is marked by brownish red, turgid, or bleached white areas on the leaf blade. Young leaves rarely display damage, whereas fully expanded leaves are very sensitive.

Ozone: Common symptoms of O_3 injury are very small, irregularly shaped spots that are dark brown to black (stipple-like) or light tan to white (fleck-like) on the upper leaf surface. Very young and old leaves are normally resistant to ozone. Recently matured leaves are most susceptible. Injury is usually more pronounced at the leaf tip and along the margins. With severe damage, symptoms may extend to the lower leaf surface.

Peroxyacetyl nitrate: Typically, PAN affects the under-leaf surface of newly matured leaves and causes bronzing, glazing, or silvering on the lower surface of sensitive leaf areas. The leaf apex of broad-leaved plants becomes sensitive to PAN approximately five days after leaf emergence. About four leaves on a shoot are sensitive at any one time. PAN toxicity is specific for tissue in a particular stage of development. Only with successive exposure to PAN will the entire leaf develop injury. Injury may consist of bronzing or glazing with little or no tissue collapse on the upper leaf surface. Pale green to white stipple-like areas may appear on upper and lower leaf surfaces. Complete tissue collapse in a diffuse band across the leaf is helpful in identifying PAN injury.

Chlorine: Injury from chlorine is usually of an acute type and is similar in pattern to sulfur dioxide injury. Foliar necrosis and bleaching are common. Necrosis is marginal in some species but scattered in others,

either between or along veins. Lettuce plants exhibit necrotic injury on the margins of outer leaves, which often extends in solid areas toward the center and base of the leaf. Inner leaves remain unmarked.

Ammonia: Field injury from NH_3 is primarily due to accidental spillage. Slight amounts of the gas produce color changes in the pigments of vegetable skin. The dry outer scales of red onion may become greenish or black, whereas scales of yellow or brown onion may turn dark brown.

Hydrochloric acid gas: HCl causes an acid-type burn. The usual acute response is a bleaching of tissue. Leaves of lettuce, endive, and escarole exhibit a tip burn that progresses toward the center of the leaf and soon dries out. Tomato plants develop interveinal bronzing.

Original material from Commercial Vegetable Production Recommendations, Maryland Agricultural Extension Service EB-236 (1986) and Bulletin 137 (2005).

Additional Resource H. Griffiths, *Effects of Air Pollution on Agricultural Crops* (Ontario Ministry of Agriculture, Food, and Rural Affairs, 2003), http://www.omafra.gov.on.ca/english/crops/facts/01-015.htm.

REACTION OF VEGETABLE CROPS TO AIR POLLUTANTS

Vegetable crops may be injured following exposure to high concentrations of atmospheric pollutants. Prolonged exposure to lower concentrations may also result in plant damage. Injury appears progressively as leaf chlorosis (yellowing), necrosis (death), and perhaps restricted growth and yields. On occasion, plants may be killed, but usually not until they have suffered persistent injury. Symptoms of air pollution damage vary with the individual crops and plant age, specific pollutant, concentration, duration of exposure, and environmental conditions.

RELATIVE SENSITIVTY OF VEGETABLE CROPS TO AIR POLLUTANTS

TABLE 6.1. SENSITIVITY OF VEGETABLES TO SELECTED AIR POLLUTANTS

| Pollutant | Sensitive | Intermediate | Tolerant |
|------------------|------------------|--------------|------------|
| Ozone | Bean | Carrot | Beet |
| | Broccoli | Endive | Cucumber |
| | Onion | Parsley | Lettuce |
| | Potato | Parsnip | |
| | Radish | Turnip | |
| | Spinach | | |
| | Sweet corn | | |
| | Tomato | | |
| Sulfur dioxide | Bean | Cabbage | Cucumber |
| | Beet | Pea | Onion |
| | Broccoli | Tomato | Sweet corn |
| | Brussels sprouts | | |
| | Carrot | | |
| | Endive | | |
| | Lettuce | | |
| | Okra | | |
| | Pepper | | |
| | Pumpkin | | |
| | Radish | | |
| | Rhubarb | | |
| | Spinach | | |
| | Squash | | |
| | Sweet potato | | |
| | Swiss chard | | |
| | Turnip | | |
| Fluoride | Sweet corn | | Asparagus |
| | | | Squash |
| | | | Tomato |
| Nitrogen dioxide | Lettuce | | Asparagus |
| - | | | Bean |
| PAN | Bean | Carrot | Broccoli |
| | Beet | | Cabbage |

TABLE 6.1. SENSITIVITY OF VEGETABLES TO SELECTED AIR POLLUTANTS (Continued)

| Pollutant | Sensitive | Intermediate | Tolerant |
|--------------------------------------|---|--|--|
| | Celery Endive Lettuce Mustard Pepper Spinach Sweet corn Swiss chard | | Cauliflower Cucumber Onion Radish Squash |
| Ethylene | Tomato Bean Cucumber Pea Southern pea Sweet potato Tomato | Carrot Squash | Beet Cabbage Endive Onion Radish |
| 2,4-D | Tomato | Potato | Bean Cabbage Eggplant Rhubarb |
| Chlorine Ammonia | Mustard Onion Radish Sweet corn Mustard | Bean Cucumber Southern pea Squash Tomato Tomato | Eggplant Pepper |
| Mercury vapor Hydrogen sulfide | Bean Cucumber Radish Tomato | Tomato Pepper | Mustard |

Adapted from J. S. Jacobson and A. C. Hill (eds.), Recognition of Air Pollution Injury to Vegetation (Pittsburgh: Air Pollution Control Association, 1970); M. Treshow, Environment and Plant Response (New York: McGraw-Hill, 1970); R.G. Pearson et al., Air Pollution and Horticultural Crops, Ontario Ministry of Agriculture and Food AGDEX 200/691 (1973); and H. Griffiths, Effects of Air Pollution on Agricultural Crops (Ontario Ministry of Agriculture, Food, and Rural Affairs, 2003), http://www.omafra.gov.on.ca/english/crops/facts/01-015.htm.

02 INTEGRATED PEST MANAGEMENT

BASICS OF INTEGRATED PEST MANAGEMENT

Integrated Pest Management (IPM) attempts to make the most efficient use of the strategies available to control pest populations by taking action to prevent problems, suppress damage levels, and use chemical pesticides only where needed. Rather than seeking to eradicate all pests entirely, IPM strives to prevent their development or to suppress their population numbers below levels that would be economically damaging.

Integrated means that a broad, interdisciplinary approach is taken using scientific principles of crop protection in order to fuse into a single system a variety of methods and tactics.

Pest includes insects, mites, nematodes, plant pathogens, weeds, and vertebrates that adversely affect crop quality and yield.

Management refers to the attempt to control pest populations in a planned, systematic way by keeping their numbers or damage within acceptable levels.

Effective IPM consists of four basic principles:

- 1. *Exclusion* seeks to prevent pests from entering the field in the first place.
- 2. *Suppression* refers to the attempt to suppress pests below the level at which they would be economically damaging.
- 3. Eradication strives to eliminate entirely certain pests.
- 4. *Plant resistance* stresses the effort to develop healthy, vigorous varieties that are resistant to certain pests.

In order to carry out these four basic principles, the following steps are recommended:

- 1. The identification of key pests and beneficial organisms is a necessary first step.
- 2. Preventive cultural practices are selected to minimize pest population development.
- 3. *Pest populations must be monitored* by trained scouts who routinely sample fields.

- 4. A prediction of loss and risks involved is made by setting an economic threshold. Pests are controlled only when the pest population threatens acceptable levels of quality and yield. The level at which the pest population or its damage endangers quality and yield is often called the *economic threshold*. The economic threshold is set by predicting potential loss and risks at a given pest population density.
- 5. An action decision must be made. In some cases, pesticide application is necessary to reduce the crop threat, whereas in other cases, a decision is made to wait and rely on closer monitoring.
- Evaluation and follow-up must occur throughout all stages in order to make corrections, assess levels of success, and project future possibilities for improvement.

To be effective, IPM must make use of the following tools:

- Pesticides. Some pesticides are applied preventively—for example, herbicides, fungicides, and nematicides. In an effective IPM program, pesticides are applied on a prescription basis tailored to the particular pest and chosen for minimum impact on people and the environment. Pesticides are applied only when a pest population is diagnosed as large enough to threaten acceptable levels of yield and quality and no other economic control measure is available.
- Resistant crop varieties are bred and selected when available in order to protect against key pests.
- Natural enemies are used to regulate the pest population whenever possible.
- Pheromone (sex lure) traps are used to lure and destroy male insects to help monitor populations.
- Preventive measures such as soil fumigation for nematodes and assurance of good soil fertility help provide a healthy, vigorous plant.
- *Avoidance* of peak pest populations can be brought about by a change in planting times or pest-controlling crop rotation.
- *Improved application* is achieved by keeping equipment up to date and in excellent shape.
- Other assorted cultural practices such as flooding and row and plant spacing can influence pest populations.

Resources for Integrated Pest Management:

 Pest Management (IPM), http://attra.ncat.org/attra-pub/ipm.html (2001)

- UC IPM Online—Statewide Integrated Pest Management Program, http://www.ipm.ucdavis.edu/
- The Pennsylvania Integrated Pest Management Program, http://paipm.cas.psu.edu/
- North Central Region—National IPM Network, http:// www.ipm.iastate.edu/ipm/nipmn/
- Northeastern IPM Center, http://northeastipm.org/
- Integrated Pest Management in the Southern Region, http://ipmwww.ento.vt.edu/nipmn/
- New York State Integrated Pest Management Program at Cornell University, http://www.nysipm.cornell.edu/
- IPM Florida, http://ipm.ifas.ufl.edu/

03 SOIL SOLARIZATION

BASICS OF SOIL SOLARIZATION

Soil solarization is a nonchemical pest control method that is particularly effective in areas that have high temperatures and long days for the required 4–6 weeks. In the northern hemisphere, this generally means that solarization is done during the summer months in preparation for a fall crop or for a crop in the following spring.

Soil solarization captures radiant heat energy from the sun, thereby causing physical, chemical, and biological changes in the soil. Transparent polyethylene plastic placed on moist soil during the hot summer months increases soil temperatures to levels lethal to many soil borne plant pathogens, weed seeds, and seedlings (including parasitic seed plants), nematodes, and some soil-residing mites. Soil solarization also improves plant nutrition by increasing the availability of nitrogen and other essential nutrients.

Time of Year

Highest soil temperatures are obtained when the days are long, air temperatures are high, the sky is clear, and there is no wind.

Plastic Color

Clear polyethylene should be used, not black plastic. Transparent plastic results in greater transmission of solar energy to the soil. Polyethylene should be UV stabilized so the tarp does not degrade during the solarization period.

Plastic Thickness

Polyethylene 1 mil thick is the most efficient and economical for soil heating. However, it is easier to rip or puncture and is less able to withstand high winds than thicker plastic. Users in windy areas may prefer to use plastic $1\frac{1}{2}$ –2 mil thick. Thick transparent plastic (4–6 mil) reflects more solar energy than does thinner plastic (1–2 mil) and results in slightly lower temperatures.

Preparation of the Soil

It is important that the area to be treated is level and free of weeds, plants, debris, and large clods that would raise the plastic off the ground. Maximum soil heating occurs when the plastic is close to the soil; therefore, air pockets caused by large clods or deep furrows should be avoided. Soil should be tilled as deep as possible and have moisture at field capacity.

Partial Versus Complete Soil Coverage

Polyethylene tarps may be applied in strips (a minimum of 2–3 ft wide) over the planting bed or as continuous sheeting glued, heat-fused, or held in place by soil. In some cases, strip coverage may be more practical and economical than full soil coverage, because less plastic is needed and plastic connection costs are avoided.

Soil Moisture

Soil must be moist (field capacity) for maximum effect because moisture not only makes organisms more sensitive to heat but also conducts heat faster and deeper into the soil.

Duration of Soil Coverage

Killing of pathogens and pests is related to time and temperature exposure. The longer the soil is heated, the deeper the control. Although some pest organisms are killed within days, 4–6 weeks of treatment in full sun during the summer is usually best. The upper limit for temperature is about 115°F for vascular plants, 130°F for nematodes, 140°F for fungi, and 160–212°F for bacteria.

Original material adapted from G. S. Pullman, J. E. DeVay, C. L. Elmore, and W. H. Hart, "Soil Solarization," California Cooperative Extension Leaflet 21377 (1984), and from D. O. Chellemi, "Soil Solarization for Management of Soilborne Pests," Florida Cooperative Extension Fact Sheet PPP51 (1995).

Additional Resources on Soil Solarization:

- International Workgroup on Soil Solarization and Integrated Management of Soilborne Pests, http://www.uckac.edu/iwgss//
- C. Strausbaugh Soil Solarization for Control of Soilborne Pest Problems (University of Idaho, 1996), http://www.uidaho.edu/ag/ plantdisease/soilsol.htm

- The Soil Solarization Home (Hebrew University of Jerusalem, 1998), http://agri3.huji.ac.il/~katan/
- Soil Solarization (University of California), http://ucce.ucdavis.edu/ files/filelibrary/40/942.pdf
- A. Hagan and W. Gazaway, Soil Solarization for the Control of Nematodes and Soilborne Diseases (Auburn University, 2002), http:// www.aces.edu/pubs/docs/A/ANR-0713/

04 PESTICIDE USE PRECAUTIONS

GENERAL SUGGESTIONS FOR PESTICIDE SAFETY

All chemicals are potentially hazardous and should be used carefully. Follow exactly the directions, precautions, and limitations given on the container label. Store all chemicals in a safe place where children, pets, and livestock cannot reach them. Do not reuse pesticide containers. Avoid inhaling fumes and dust from pesticides. Avoid spilling chemicals; if they are accidentally spilled, remove contaminated clothing and thoroughly wash the skin with soap and water immediately.

Observe the following rules:

- Avoid drift from the application area to adjacent areas occupied by other crops, humans, livestock, or bodies of water.
- Wear goggles, an approved respirator, and neoprene gloves when loading or mixing pesticides. Aerial applicators should be loaded by a ground crew.
- Pour chemicals at a level well below the face to avoid splashing or spilling onto the face or eyes.
- 4. Have plenty of soap and water on hand to wash contaminated skin in the event of spilling.
- 5. Change clothing and bathe after the job is completed.
- 6. Know the insecticide, the symptoms of overexposure to it, and a physician who can be called quickly. In case symptoms appear (contracted pupils, blurred vision, nausea, severe headache, dizziness), stop operations at once and contact a physician.

THE WORKER PROTECTION STANDARD (WPS)

Glossary of terms for WPS:

Agricultural employer: Any person who:

- employs or contracts for the services of agricultural workers (including themselves and family members) for any type of compensation to perform tasks relating to the production of agricultural plants;
- owns or operates an agricultural establishment that uses such workers;

- employs pesticide handlers (including family members) for any type of compensation; or
- is self-employed as a pesticide handler.
- Agricultural establishment: Any farm, greenhouse, nursery, or forest that produces agricultural plants.
- Agricultural establishment owner: Any person who owns, leases, or rents an agricultural establishment covered by the Worker Protection Standard (WPS).
- Agricultural worker: Any person employed by an agricultural employer to do tasks such as harvesting, weeding, or watering related to the production of agricultural plants on a farm, forest, nursery, or greenhouse. By definition, agricultural workers do not apply pesticides or handle pesticide containers or equipment. Any employee can be an agricultural worker while performing one task and a pesticide handler while performing a different task.
- *Immediate family:* The spouse, children, stepchildren, foster children, parents, stepparents, foster parents, brothers and sisters of an agricultural employer.
- Personal protective equipment (PPE): Clothing and equipment, such as goggles, gloves, boots, aprons, coveralls and respirators, that provide protection from exposure to pesticides.
- Pesticide handler: Any person employed by an agricultural establishment to mix, load, transfer, or apply pesticides or do other tasks that involve direct contact with pesticides.
- Restricted entry interval (REI): The time immediately after a pesticide application when entry into the treated area is limited. Lengths of restricted entry intervals range between 4 and 72 hours. The exact amount of time is product specific and indicated on the pesticide label.

Adapted from O. N. Nesheim and T. W. Dean, "The Worker Protection Standard," in S. M. Olson and E. H. Simonne (eds.), *Vegetable Production Handbook for Florida* (Florida Cooperative Extension Service, 2005–2006), http://edis.ifas.ufl.edu/CV138.

DESCRIPTION OF THE WORKER PROTECTION STANDARD

The worker protection standard (WPS) is a set of regulations issued by the U.S. Environmental Protection Agency (EPA) designed to protect agricultural workers and pesticide handlers from exposure to pesticides.

http://www.epa.gov/pesticides/safety/workers/PART170.htm

The WPS applies to all agricultural employers whose employees are involved in the production of agricultural plants on a farm, forest, nursery, or greenhouse. The employers include owners or managers of farms, forests, nurseries, or greenhouses as well as commercial (custom) applicators and crop advisors who provide services for the production of agricultural plants on these sites. The WPS requires that specific protections be provided to workers and pesticide handlers to prevent pesticide exposure. The agricultural employer is responsible for providing those protections to employees.

Information at a Central Location

An information display at a central location must be provided and contain:

- 1. An approved EPA safety poster showing how to keep pesticides from a person's body and how to clean up any contact with a pesticide
- 2. Name, address, and telephone number of the nearest emergency medical facility
- 3. Information about each pesticide application, including description of treated area, product name, EPA registration number of product, active ingredient of pesticide, time and date of application, and the restricted entry interval (REI) for the pesticide

Pesticide Safety Training

Employers must provide pesticide safety training for pesticide handlers and agricultural workers unless the handler or worker is a certified pesticide applicator. Workers must receive training within 5 days of beginning work.

Decontamination Areas Must Provide:

- 1. Water for washing and eye flushing
- 2. Soap
- 3. Single-use towels
- 4. Water for whole-body wash (pesticide handler sites only)
- 5. Clean coveralls (pesticide handler sites only)
- 6. Provide each handler at least 1 pt clean water for flushing eyes

Restricted Entry Interval

Pesticides have restricted entry intervals, a period after a pesticide application during which employers must keep everyone, except

appropriately trained and equipped handlers, out of treated areas. Employers must orally inform all of their agricultural workers who will be within a quarter-mile of a treated area. For certain pesticides, treated fields must also be posted with a WPS poster.

Personal Protective Equipment

Personal protective equipment (PPE) must be provided by the employer to all pesticide handlers.

- All PPE must be clean, in operating condition, used correctly, inspected each day before use, and repaired or replaced as needed.
- 2. Respirators must fit correctly and filters or canisters replaced at recommended intervals.
- 3. Handlers must be warned about symptoms of heat illness when wearing PPE.
- 4. Handlers must be provided clean, pesticide-free areas to store PPE.
- 5. Contaminated PPE must not be worn or taken home and must be cleaned separate from other laundry.
- 6. Employers are responsible for providing clean PPE for each day.
- Coveralls contaminated with undiluted Danger or Warning category pesticide must be discarded.

Adapted from O. N. Nesheim and T. W. Dean, "The Worker Protection Standard," http://edis.ifas. ufl.edu/CV138, and O. N. Nesheim, "Interpreting PPE Statements on Pesticide Labels," in S. M. Olson and E. H. Simonne (eds.), Vegetable Production Handbook for Florida (Florida Cooperative Extension Service, 2005–2006), http://edis.ifas.ufl.edu/CV285.

Additional resource on the Worker Protection Standard:

http://www.epa.gov/pesticides/safety/workers/PART170.htm

ADDITIONAL INFORMATION ON SAFETY AND RULES AFFECTING PESTICIDE USE

Recordkeeping

Growers are required to keep records on applications of restricted-use pesticides.

http://www.environment.nsw.gov.au/envirom/recordkeeping.htm

Sample recordkeeping forms can be found at:

http://www.epa.nsw.gov.au/resources/pesticidesrkform.pdf

SARA Title III Emergency Planning and Community Right-to-Know Act

This law sets rules for farmers to inform the proper authorities about storage of extremely hazardous materials. Each state has related SARA Title III statutes.

Lists of chemicals are available at:

http://www.epa.gov/ceppo/pubs/title3.pdf

Right-to-Know

Employees have a right to know about chemical use on the farm. Right-to-know training is typically provided through the County Extension Office.

Endangered Species Act

The EPA has determined threshold pesticide application rates that may affect listed species. This information is presented on the pesticide label.

http://www.fws.gov/endangered/esa.html http://www.epa.gov/region5/defs/html/esa.htm

Invasive Species

An *invasive species* is defined as a species that is non-native (or alien) to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm, or harm to human health. Some websites:

http://www.fws.gov/contaminants/Issues/InvasiveSpecies.cfm

http://invasivespeciesinfo.gov

http://aquat1.ifas.ufl.edu

http://plants.nrcs.usda.gov/cgi_bin/topics.cgi?earl=noxious.cgi

http://www.invasive.org/

PESTICIDE HAZARDS TO HONEYBEES

Honeybees and other bees are necessary for pollination of vegetables in the gourd family—cantaloupe and other melons, cucumber, pumpkin, squash, and watermelon. Bees and other pollinating insects are necessary for all the insect-pollinated vegetables grown for seed production. Some pesticides are extremely toxic to bees and other pollinating insects, so certain precautions are necessary to avoid injury to them.

Recommendations for Vegetable Growers and Pesticide Applicators to Protect Rees

- Participate actively in areawide integrated crop management programs.
- 2. Follow pesticide label directions and recommendations.
- 3. Apply hazardous chemicals in late afternoon, night, or early morning (generally 6 P.M. to 7 A.M.) when honeybees are not actively foraging. Evening applications are generally somewhat safer than morning applications.
- 4. Use pesticides that are relatively nonhazardous to bees whenever this is consistent with other pest-management strategies. Choose the least hazardous pesticide formulations or tank mixes.
- Become familiar with bee foraging behavior and types of pesticide applications that are hazardous to bees.
- 6. Know the location of all apiaries in the vicinity of fields to be sprayed.
- Avoid drift, overspray, and dumping of toxic materials in noncultivated areas.
- 8. Survey pest populations and be aware of current treatment thresholds in order to avoid unnecessary pesticide use.
- 9. Determine if bees are foraging in target areas so protective measures can be taken.

TOXICITY OF CHEMICALS USED IN PEST CONTROL

The danger in handling pesticides does not depend exclusively on toxicity values. Hazard is a function of both toxicity and the amount and type of exposure. Some chemicals are very hazardous from dermal (skin) exposure as well as oral (ingestion). Although inhalation values are not given, this

type of exposure is similar to ingestion. A compound may be highly toxic but present little hazard to the applicator if the precautions are followed carefully.

Toxicity values are expressed as acute oral LD_{50} in terms of milligrams of the substance per kilogram (mg/kg) of test animal body weight required to kill 50% of the population. The acute dermal LD_{50} is also expressed in mg/kg. These acute values are for a single exposure and not for repeated exposures such as may occur in the field. Rats are used to obtain the oral LD_{50} , and the test animals used to obtain the dermal values are usually rabbits.

TABLE 6.2. CATEGORIES OF PESTICIDE TOXICITY¹

| | | LD ₅₀ Val | LD ₅₀ Value (mg/kg) | |
|----------------------|--|--------------------------------------|--|--|
| Categories | Signal Word | Oral | Dermal | |
| I II III IV | Danger–Poison Warning Caution None ² | 0–50 50–500 500–5,000 5,000 | 0-200 200-2,000 2,000-20,000 20,000 | |

¹EPA-accepted categories.

Resources on Toxicity of Pesticides

- Commercial Vegetable Production Recommendations, Maryland Agricultural Extension Service Bulletin 137 (2005).
- L. Moses, R. Meister, and C. Sine, Farm Chemicals Handbook '99 (Willoughby, Ohio: Meister, 1999).

PESTICIDE FORMULATIONS

Several formulations of many pesticides are available commercially. Some are emulsifiable concentrates, flowables, wettable powders, dusts, and granules. After any pesticide recommendation, one of these formulations is suggested; however, unless stated to the contrary, equivalent rates of

 $^{^2}$ No signal word required based on acute toxicity; however, products in this category usually display "Caution."

another formulation or concentration of that pesticide can be used. In most cases, pesticide experts suggest that sprays rather than dusts be applied to control pests of vegetables. This is because sprays allow better control and result in less drift.

PREVENTING SPRAY DRIFT

Pesticides sprayed onto soil or crops may be subject to movement or drift away from the target, due mostly to wind. Drift may lead to risks to nearby people and wildlife, damage to nontarget plants, and pollution of surface water or groundwater.

Factors That Affect Drift

- Droplet size. Smaller droplets can drift longer distances. Droplet size
 can be managed by selecting the proper nozzle type and size,
 adjusting the spray pressure, and increasing the viscosity of the spray
 mixture.
- 2. Equipment adjustments. Routine calibration of spraying equipment and general maintenance should be practiced. Equipment can be fitted with hoods or shields to reduce drift away from the sprayed area.
- Weather conditions. Spray applicators must be aware of wind speed and direction, relative humidity, temperature, and atmospheric stability at time of spraying.

Spraying Checklist to Minimize Drift

- 1. Do not spray on windy days (>12 mph).
- Avoid spraying on extremely hot and dry days.
- 3. Use minimum required pressure.
- 4. Select correct nozzle size and spray pattern.
- 5. Keep the boom as close as possible to the target.
- 6. Install hoods or shields on the spray boom.
- Leave an unsprayed border of 50-100 ft near water supplies, wetlands, neighbors, and non-target crops.
- Spray when wind direction is favorable for keeping drift off of nontarget areas.

05 PESTICIDE APPLICATION AND EQUIPMENT

ESTIMATION OF CROP AREA

To calculate approximately the acreage of a crop in the field, multiply the length of the field by the number of rows or beds. Divide by the factor for spacing of beds.

Examples: Field 726 ft long with 75 rows 48 in. apart.

$$\frac{726 \times 75}{10890} = 5 \text{ acres}$$

Field 500 ft long with 150 beds on 40-in. centers.

$$\frac{500 \times 150}{13068} = 5.74 \text{ acres}$$

TABLE 6.3. FACTORS USED IN CALCULATING TREATED CROP AREA

| cing (in.) | Factor |
|------------|--------|
| 12 | 43,560 |
| 18 | 29,040 |
| 24 | 21,780 |
| 30 | 17,424 |
| 36 | 14,520 |
| 40 | 13,068 |
| 42 | 12,445 |
| 48 | 10,890 |
| 60 | 8,712 |
| 72 | 7,260 |
| 84 | 6,223 |

TABLE 6.4. DISTANCE TRAVELED AT VARIOUS TRACTOR SPEEDS

| mph | ft/min | mph | ft/min |
|-----|--------|-----|--------|
| | | | |
| 1.0 | 88 | 3.1 | 273 |
| 1.1 | 97 | 3.2 | 282 |
| 1.2 | 106 | 3.3 | 291 |
| 1.3 | 114 | 3.4 | 299 |
| 1.4 | 123 | 3.5 | 308 |
| 1.5 | 132 | 3.6 | 317 |
| 1.6 | 141 | 3.7 | 325 |
| 1.7 | 150 | 3.8 | 334 |
| 1.8 | 158 | 3.9 | 343 |
| 1.9 | 167 | 4.0 | 352 |
| 2.0 | 176 | 4.1 | 361 |
| 2.1 | 185 | 4.2 | 370 |
| 2.2 | 194 | 4.3 | 378 |
| 2.3 | 202 | 4.4 | 387 |
| 2.4 | 211 | 4.5 | 396 |
| 2.5 | 220 | 4.6 | 405 |
| 2.6 | 229 | 4.7 | 414 |
| 2.7 | 237 | 4.8 | 422 |
| 2.8 | 246 | 4.9 | 431 |
| 2.9 | 255 | 5.0 | 440 |
| 3.0 | 264 | | |

CALCULATIONS OF SPEED OF EQUIPMENT AND AREA WORKED

To review the actual performance of a tractor, determine the number of seconds required to travel a certain distance. Then use the formula

$$speed~(mph) = \frac{distance~traveled~(ft) \times 0.682}{time~to~cover~distance~(sec)}$$

or the formula

$$speed~(mph) = \frac{distance~traveled~(ft)}{time~to~cover~distance~(sec) \times 1.47}$$

Another method is to walk beside the machine counting the number of normal paces (2.93 ft) covered in 20 seconds. Move decimal point 1 place. Result equals tractor speed (mph).

Example: 15 paces/20 sec = 1.5 mph.

The working width of an implement multiplied by mph equals the number of acres covered in 10 hr. This includes an allowance of 17.5% for turning at the ends of the field. By moving the decimal point 1 place, which is equivalent to dividing by 10, the result is the acreage covered in 1 hr.

Example: A sprayer with a 20-ft boom is operating at 3.5 mph. Thus, 20 \times 3.5 = 70 acres/10 hr or 7 acres/hr.

TABLE 6.5. APPROXIMATE TIME REQUIRED TO WORK AN ACRE¹

| Rate (mph): Rate (ft/min): | 1 88 | 2 176 | 3 264 | 4 352 | 5 440 | 10 880 | |
|--|--------------------------------------|----------|----------|----------|----------|-----------|--|
| Effective Working Width of Equipment (in.) | Approximate Time Required (min/acre) | | | | | | |
| 18 | 440 | 220 | 147 | 110 | 88 | 44 | |
| 24 | 330 | 165 | 110 | 83 | 66 | 33 | |
| 36 | 220 | 110 | 73 | 55 | 44 | 22 | |
| 40 | 198 | 99 | 66 | 50 | 40 | 20 | |
| 42 | 189 | 95 | 63 | 47 | 38 | 19 | |
| 48 | 165 | 83 | 55 | 41 | 33 | 17 | |
| 60 | 132 | 66 | 44 | 33 | 26 | 13 | |
| 72 | 110 | 55 | 37 | 28 | 22 | 11 | |
| 80 | 99 | 50 | 33 | 25 | 20 | 10 | |
| 84 | 94 | 47 | 31 | 24 | 19 | 9 | |
| 96 | 83 | 42 | 28 | 21 | 17 | 8 | |
| 108 | 73 | 37 | 24 | 19 | 15 | 7 | |
| 120 | 66 | 33 | 22 | 17 | 13 | 6 | |
| 240 | 33 | 17 | 11 | 8 | 7 | 3 | |
| 360 | 22 | 11 | 7 | 6 | 4 | 2 | |

 $^{^1\}mathrm{These}$ figures are calculated on the basis of 75% field efficiency to allow for turning and other lost time.

USE OF PESTICIDE APPLICATION EQUIPMENT

Ground Application

Boom-type Sprayers

High-pressure, high-volume sprayers have been used for row-crop pest control for many years. Now a trend exists toward the use of sprayers that utilize lower volumes and pressures.

Airblast-type Sprayers

Airblast sprayers are used in the vegetable industry to control insects and diseases. Correct operation of an airblast sprayer is more critical than for a

boom-type sprayer. Do not operate an airblast sprayer under high wind conditions. Wind speed below 5 mph is preferable unless it becomes necessary to apply the pesticide for timely control measures, but drift and nearby crops must be considered. Do not overextend the coverage of the machine.

Considerable visible mist from the machine moves into the atmosphere and does not deposit on the plant. If in doubt, use black plastic indicator sheets in the rows to determine deposit and coverage before a pest problem appears as evidence. Use correct gallonage and pressures to obtain proper droplet size and ensure uniform coverage across the effective swath width. Adjust the vanes and nozzles on the sprayer unit to give best coverage. Vane adjustment must occur in the field, depending on terrain, wind, and crop. Cross-drives in the field allow the material to be blown down the rows instead of across them and help give better coverage in some crops, such as staked or trellised tomato.

Air-boom Sprayers

These sprayers combine the airblast spray with the boom spray delivery characteristics. Air-boom sprayers are becoming popular with vegetable producers in an effort to achieve high levels of spray coverage with minimal quantities of pesticide.

Electrostatic Sprayers

These sprayers create an electrical field through which the spray droplets move. Charged spray droplets are deposited more effectively onto plant surfaces, and less drift results.

Aerial Application

Spraying should not be done when wind is more than 6 mph. A slight crosswind during spraying is advantageous in equalizing the distribution of the spray within the swath and between swaths. Proper nozzle angle and arrangements along the boom are critical and necessary to obtain proper distribution at ground level. Use black plastic indicator sheets in the rows to determine deposit and coverage patterns. Cover a swath no wider than is reasonable for the aircraft and boom being used. Fields of irregular shape or topography and ones bounded by woods, power lines, or other flight hazards should not be sprayed by aircraft.

CALIBRATION OF FIELD SPRAYERS

Width of Boom

The boom coverage is equal to the number of nozzles multiplied by the space between two nozzles.

Ground Speed (mph)

Careful control of ground speed is important for accurate spray application. Select a gear and throttle setting to maintain constant speed. A speed of 2–3 mph is desirable. From a running start, mark off the beginning and ending of a 30-sec run. The distance traveled in this 30-sec period divided by 44 equals the speed in mph.

Sprayer Discharge (gpm)

Run the sprayer at a certain pressure, and catch the discharge from each nozzle for a known length of time. Collect all the discharge and measure the total volume. Divide this volume by the time in minutes to determine discharge in gallons per minute.

Before Calibrating

- 1. Thoroughly clean all nozzles, screens, etc., to ensure proper operation.
- 2. Check that all nozzles are the same.
- Check the spray patterns of all nozzles for uniformity. Check the volume of delivery by placing similar containers under each nozzle. Replace nozzles that do not have uniform patterns or do not fill containers at the same rate.
- Select an operating speed. Note the tachometer reading or mark the throttle setting. When spraying, be sure to use the same speed as used for calibrating.
- 5. Select an operating pressure. Adjust to desired pressure (pounds per square in. [psi]) while the pump is operating at normal speed and water is actually flowing through the nozzles. This pressure should be the same during calibration and field spraying.

Calibration (Jar Method)

Either a special calibration jar or a homemade one can be used. If you buy one, carefully follow the manufacturer's instructions.

Make accurate speed and pressure readings and jar measurements. Make several checks.

Any 1-qt or larger container, such as a jar or measuring cup, if calibrated in floz, can easily be used in the following manner:

 Measure a course on the same type of surface (sod, plowed, etc.) and same type of terrain (hilly, level, etc.) as that to be sprayed, according to nozzle spacing as follows:

TABLE 6.6. COURSE LENGTH SELECTED BASED ON NOZZLE SPACING

| Nozzle spacing (in.) | 16 | 20 | 24 | 28 | 32 | 36 | 40 |
|----------------------|-----|-----|-----|-----|-----|-----|-----|
| Course length (ft) | 255 | 204 | 170 | 146 | 127 | 113 | 102 |

- 2. Time the seconds it takes the sprayer to cover the measured distance at the desired speed.
- 3. With the sprayer standing still, operate at selected pressure and pump speed. Catch the water from several nozzles for the number of seconds measured in step 2.
- 4. Determine the average output per nozzle in ounces. The ounces per nozzle equal the gal/acre applied for one nozzle per spacing.

Calibration (Boom or Airblast Sprayer)

- Fill sprayer with water.
- Spray a measured area (width of area covered × distance traveled) at constant speed and pressure selected from manufacturer's information.
- 3. Measure amount of water necessary to refill tank (gal used).
- 4. Multiply gallons used by 43,560 and divide by the number of sq ft in area sprayed. This gives gal/acre.

$$gal/acre = \frac{gal \ used \times 43,560}{area \ sprayed \ (sq \ ft)}$$

5. Add correct amount of spray material to tank to give the recommended rate per acre.

EXAMPLE

Assume: 10 gal water used to spray an area 660 ft long and 20 ft wide

Tank size: 100 gal

Spray material: 2 lb (actual)/acre

Calculation:

$$\frac{\text{gal used} \times 43,560}{\text{area sprayed (sq ft)}} = \frac{10 \times 43,560}{660 \times 20} = 33 \text{ gal/acre}$$

$$\frac{tank \ capacity}{gal/acre} \ \frac{100 \ (tank \ size)}{33} = 3.03 \ acres \ sprayed \ per \ tank$$

 3.03×2 (lb/acre) = 6.06 lb material per tank

If 80% material is used:

$$\frac{6.06}{0.8}$$
 = 7.57 lb material needed per tank to give 2 lb/acre rate

Adapted from Commercial Vegetable Production Recommendations (Maryland Agricultural Extension Service Bulletin 137, 2005), http:///hortweb.cas.psu.edu/extension/images/PA%2005%20commercial%20veg%20Recommends.pdf.

CALIBRATION OF GRANULAR APPLICATORS

Sales of granular fertilizer, herbicides, insecticides, etc., for application through granular application equipment have been on the increase.

Application rates of granular application equipment are affected by several factors: gate openings or settings, ground speed of the applicator, shape and size of granular material, and roughness of the ground.

Broadcast Application

- 1. From the label, determine the application rate.
- 2. From the operator's manual, set the dial or feed gate to apply desired rate.
- 3. On a level surface, fill the hopper to a given level and mark this level.
- Measure the test area—length of run depends on size of equipment. It need not be one long run but can be multiple runs at shorter distances.

- Apply material to measured area, operating at the speed applicator will travel during application.
- Weigh the amount of material required to refill the hopper to the marked level.
- 7. Determine the application rate:

$$\frac{\text{area covered} =}{\frac{\text{number of runs} \times \text{length of run} \times \text{width of application}}{43,560}}$$

$$\frac{\text{application rate} =}{\text{amount applied (pounds to refill hopper)}}$$

$$\frac{\text{area covered}}{\text{area covered}}$$

Note: Width of application is width of the spreader for drop or gravity spreaders. For spinner applicators, it is the working width (distance between runs). Check operator's manual for recommendations, generally one-half to three-fourths of overall width spread.

Example:

Assume: 50 lb/acre rate

Test run: 200 ft Four runs made

Application width: 12 ft 11.5 lb to refill hopper

Calculation:

area covered =
$$\frac{4\times200\times12}{43,560}$$
 = 0.22 acre application rate = $\frac{11.5}{0.22}$ = 52.27 lb

8. If application rate is not correct, adjust feed gate opening and recheck.

Band Application

- 1. From the label, determine the application rate.
- From the operator's manual, determine the applicator setting and adjust accordingly.

- 3. Fill the hopper half full.
- 4. Operate the applicator until all units are feeding.
- 5. Stop the applicator; remove the feed tubes at the hopper.
- 6. Attach paper or plastic bags over the hopper openings.
- Operate the applicator over a measured distance at the speed equipment will be operated.
- 8. Weigh and record the amount delivered from each hopper. (Compare to check that all hoppers deliver the same amount.)
- 9. Calculate the application rate:

area covered in bands =
$$\frac{\text{length of run} \times \text{band width} \times \text{number of bands}}{43,560}$$

Application Rate

Changing from Broadcast to Band Application

$$\frac{band\ width\ in\ in.}{row\ spacing\ in\ in.} \times \\ xrate \\ per\ acre \\ = amount\ needed\ per\ acre$$

Adapted from Commercial Vegetable Production Recommendations (Maryland Agricultural Extension Service Bulletin 137, 2005), http:///hortweb.cas.psu.edu/extension/images/PA%2005%20commercial%20veg%20Recommends.pdf.

CALIBRATION OF AERIAL SPRAY EQUIPMENT

Calibration

$$acres \ covered = \frac{length \ of \ swath \ (miles) \times width \ (ft)}{8.25}$$

$$acres/min = \frac{2 \times swath \ width \times mph}{1000}$$

$$GPM = \frac{2 \times swath \ width \times mph \times gal/acre}{1000}$$

Adapted from O. C. Turnquist et al., Weed, Insect, and Disease Control Guide for Commercial Vegetable Growers, Minnesota Agricultural Extension Service Special Report 5 (1978).

Resources on Calibration of Aerial Sprayers

- D. Overhults, Applicator Training Manual for Aerial Application of Pesticides (University of Kentucky), http://www.uky.edu/Agriculture/ PAT/Cat11/Cat11.htm.
- Agricultural Aircraft Calibration and Setup for Spraying (Kansas State University Publication MF-1059, 1992), http:// www.oznet.ksu.edu/library/ageng2/mf1059.pdf.

CALIBRATION OF DUSTERS

Select a convenient distance that multiplied by the width covered by the duster, both expressed in feet, equals a convenient fraction of an acre. With the hopper filled to a marked level, operate the duster at this distance. Take a known weight of dust in a bag or other container and refill hopper to the marked level. Weigh the dust remaining in the container. The difference is the quantity of dust applied to the fraction of an acre covered.

Example:

Distance duster is operated \times width covered by duster = area dusted

= 108.9 ft × 10 ft = 1089 sq ft
$$\frac{1089 \text{ sq ft}}{43,560} = \frac{1}{40} \text{ acre}$$

If it takes 1 lb dust to refill the hopper, the rate of application is 40 lb/acre.

MORE INFORMATION ON CALIBRATION OF SPRAYERS

Florida

http://edis.ifas.ufl.edu/WG013

 $http://edis.ifas.ufl.edu/TOPIC_Herbicide_Calibration_and_Application \\ http://edis.ifas.ufl.edu/TOPIC_Calibration$

Minnesota

http://www.extension.umn.edu/distribution/cropsystems/DC3885.html

North Dakota

http://www.ext.nodak.edu/extpubs/ageng/machine/ae73-5.htm

Other

http://www.dupont.com/ag/vm/literature/K-04271.pdf

HAND SPRAYER CALIBRATION

Ohio

http://ohioline.osu.edu/for-fact/0020.html

Colorado

http://www.co.larimer.co.us/publicworks/weeds/calibration.htm

SPRAY EQUIVALENTS AND CONVERSIONS

Pesticide containers give directions usually in terms of pounds or gallons of material in 100 gal water. The following tables make the conversion for smaller quantities of spray solution easy.

TABLE 6.7. SOLID EQUIVALENT TABLE

| 100 gal | 25 gal | 5 gal | 1 gal |
|---------|--------|---------------------------------|------------------|
| 4 oz | 1 oz | ³ / ₁₆ oz | ½ oz |
| 8 oz | 2 oz | ³ ∕8 oz | 1 tsp |
| 1 lb | 4 oz | ⁷ ∕8 oz | 2 tsp |
| 2 lb | 8 oz | $1^{3}/_{4}$ oz | 4 tsp |
| 3 lb | 12 oz | $2^{3}/8$ oz | 2 tbsp |
| 4 lb | 1 lb | $3\frac{1}{4}$ oz | 2 tbsp + 2 tsp |

TABLE 6.8. LIQUID EQUIVALENT TABLE

| 100 gal | 25 gal | 5 gal | 1 gal |
|--|---|---|--|
| 1 gal 2 qt 1 qt 1½ pt 1 pt 8 oz 4 oz | $egin{array}{lll} 1 & 	ext{qt} \\ 1 & 	ext{pt} \\ lac{1}{2} & 	ext{pt} \\ 6 & 	ext{oz} \\ 4 & 	ext{oz} \\ 2 & 	ext{oz} \\ 1 & 	ext{oz} \\ \end{array}$ | 6½ oz 3¼ oz 1% oz 1¼ oz ½ oz ½ oz 14 oz | 1½ oz 5% oz 5/16 oz ½ oz 3/16 oz ½ tsp ½ tsp |

TABLE 6.9. DILUTION OF LIQUID PESTICIDES TO VARIOUS CONCENTRATIONS

| Dilution | 1 gal | 3 gal | 5 gal |
|-----------------------------------|---|---|---|
| 1:100 1:200 1:800 1:1000 | $2 	ext{ tbsp} + 2 	ext{ tsp}$ $4 	ext{ tsp}$ $1 	ext{ tsp}$ $\frac{3}{4} 	ext{ tsp}$ | $^{1\!/_{2}}$ cup $^{1\!/_{4}}$ cup 1 tbsp $^{21\!/_{2}}$ tsp | $\frac{3}{4}$ cup + 5 tsp $\frac{6}{2}$ tbsp 1 tbsp + 2 tsp 1 tbsp + 1 tsp |

TABLE 6.10. PESTICIDE DILUTION CHART

Amount of formulation necessary to obtain various amounts of active ingredients.

Amount of formulation (at left) needed to obtain the following amounts of active ingredients

| Insecticide Formulation | ½ lb | ½ lb | ³ ⁄ ₄ lb | 1 lb |
|-------------------------------------|-----------------|-----------------|--------------------------------|---------|
| 1% dust | 25 | 50 | 75 | 100 |
| 2% dust | $12\frac{1}{2}$ | $\frac{30}{25}$ | $37\frac{1}{2}$ | 50 |
| 5% dust | 5 | 10 | 15 | 20 |
| 10% dust | $2^{1/2}$ | 5 | $7\frac{1}{2}$ | 10 |
| 15% wettable powder | 12/3 lb | 3⅓ lb | 5 lb | 62/3 lb |
| 25% wettable powder | 1 lb | 2 lb | 3 lb | 4 lb |
| 40% wettable powder | 5% lb | 11/4 lb | 17/8 lb | 2½ lh |
| 50% wettable powder | ½ lb | 1 lb | 1½ lb | 2 lb |
| 73% wettable powder | ½ lb | ²⁄₃ lb | 1 lb | 1½ lb |
| 23–25% liquid | 1 pt | 1 qt | 3 pt | 2 qt |
| concentrate (2 lbs | | | | |
| active ingredient/gal) | 1/ | 14 | 11/4 | 1 |
| 42–46% liquid concentrate (4 lbs | ½ pt | 1 pt | $1\frac{1}{2}$ pt | 1 qt |
| active ingredient/gal) | | | | |
| 60–65% liquid | ¹⁄₃ pt | ²⁄₃ pt | 1 pt | 1⅓ pt |
| concentrate (6 lbs | | _ | _ | _ |
| active ingredient/gal) | | | | |
| 72–78% liquid | ¹⁄₄ pt | ½ pt | 3∕4 pt | 1 pt |
| concentrate (8 lbs | | | | |
| active ingredient/gal) | | | | |
| | | | | |

TABLE 6.11. PESTICIDE APPLICATION RATES FOR SMALL CROP PLANTINGS

| Distance Between Rows (ft) | Amount (gal/acre) | Amount (per 100 ft of row) | Length of Row Covered (ft/gal) |
|-------------------------------|-------------------|-------------------------------|--------------------------------------|
| 1 | 75 | 22 oz | 581 |
| | 100 | 30 oz | 435 |
| | 125 | 1 qt 5 oz | 348 |
| | 150 | 1 qt 12 oz | 290 |
| | 175 | 1 qt 20 oz | 249 |
| | 200 | 1 qt 27 oz | 218 |
| 2 | 75 | 1 qt 12 oz | 290 |
| | 100 | 1 qt 27 oz | 218 |
| | 125 | 2 qt 10 oz | 174 |
| | 150 | 2 qt 24 oz | 145 |
| | 175 | 3 qt 7 oz | 124 |
| | 200 | 3 qt 21 oz | 109 |
| 3 | 75 | 2 qt 2 oz | 194 |
| | 100 | 2 qt 24 oz | 145 |
| | 125 | 3 qt 14 oz | 116 |
| | 150 | 4 qt 4 oz | 97 |
| | 175 | 4 qt 26 oz | 83 |
| | 200 | 5 qt 16 oz | 73 |

GUIDELINES FOR EFFECTIVE PEST CONTROL

Often, failure to control a pest is blamed on the pesticide when the cause lies elsewhere. Some common reasons for failure follow:

- 1. Delaying applications until pests are already well established.
- 2. Making applications with insufficient gallonage or clogged or poorly arranged nozzles.
- 3. Selecting the wrong pesticide.

The following points are suggested for more effective pest control:

- Inspect fields regularly. Frequent examinations (at least twice per week) help determine the proper timing of the next pesticide application.
- 2. Control insects and mites according to economic thresholds or schedule. Economic thresholds assist in determining whether pesticide applications or other management actions are needed to avoid economic loss from pest damage. Thresholds for insect pests are generally expressed as a numerical count of a given life stage or as a damage level based on certain sampling techniques. They are intended to reflect the population size that would cause economic damage and thus warrant the cost of treatment. Guidelines for other pests are usually based on the field history, crop development, variety, weather conditions, and other factors.

Rather than using economic thresholds, many pest problems can be predicted to occur at approximately the same time year after year. One application before buildup often eliminates the need for several applications later in the season. Often, less toxic and safer-to-handle chemicals are effective when pests are small in size and population.

3. Take weather conditions into account. Spray only when wind velocity is less than 10 mph. Dust only when it is perfectly calm. Do not spray when sensitive plants are wilted during the heat of the day. If possible, make applications when ideal weather conditions prevail.

Biological insecticides are ineffective in cool weather. Some pyrethroid insecticides (permethrin) do not perform well when field temperatures reach 85°F and above. Best control results from these insecticides are achieved when the temperature is in the 70s or low 80s (evening or early morning).

Sprinkler irrigation washes pesticide deposits from foliage. Wait at least 48 hr after pesticide application before sprinkler irrigating. More frequent pesticide applications may be needed during and after periods of heavy rainfall.

4. Strive for adequate coverage of plants. The principal reason aphids, mites, cabbage loopers, and diseases are serious pests is that they occur beneath leaves, where they are protected from spray deposit or dust particles. Improved control can be achieved by adding and arranging nozzles so the application is directed toward the plants from the sides as well as from the top. In some cases, nozzles should be arranged so the application is directed beneath the leaves. As the season progresses, plant size increases, and so does the need for increased spray gallonage to ensure adequate coverage. Applying sprays with sufficient spray volume and pressure is important. Sprays from high-volume, high-pressure rigs (airblast) should be applied at

- 40–100 gal/acre at approximately 400 psi pressure. Sprays from low-volume, low-pressure rigs (boom type) should be applied at 50–100 gal/acre at approximately 100–300 psi pressure.
- 5. Select the proper pesticide. Know the pests to be controlled and choose the recommended pesticide and rate of application.

For certain pests that are extremely difficult to control or are resistant, it may be important to alternate labeled insecticides, especially with different classes of insecticides; for example, alternate a pyrethroid insecticide with either a carbamate or an organophosphate insecticide.

- 6. Assess pesticide compatibility. To determine if two pesticides are compatible, use the following jar test before tank-mixing pesticides or pesticides and fluid fertilizers:
 - a. Add 1 pt water or fertilizer solution to a clean quart jar. Then add the pesticide to the water or fertilizer solution in the same proportion as used in the field.
 - b. To a second clean quart jar, add 1 pt water or fertilizer solution. Then add ½ tsp of an adjuvant to keep the mixture emulsified. Finally, add the pesticide to the water-adjuvant or fertilizer-adjuvant in the same proportion as to be used in the field.
 - c. Close both jars tightly and mix thoroughly by inverting 10 times. Inspect the mixtures immediately and again after standing for 30 min. If the mix in either jar remains uniform for 30 min, the combination can be used. If either mixture separates but readily remixes, constant agitation is required. If nondispersible oil, sludge, or clumps of solids form, do not use the mixture.
- Calibrate application equipment. Periodic calibration of sprayers, dusters, and granule distributors is necessary to ensure accurate delivery rates of pesticides per acre. See pages 333–338.
- 8. Select correct sprayer tips. The selection of proper sprayer tips for use with various pesticides is very important. Flat fan-spray tips are designed for preemergence and postemergence application of herbicides. They can also be used with insecticides, fertilizers, and other pesticides. Flat fan-spray tips produce a tapered-edge spray pattern for uniform coverage where patterns overlap. Some flat fan-spray tips (SP) are designed to operate at low pressure (15–40 psi) and are usually used for preemergence herbicide applications. These lower pressures result in large spray particles than those from standard flat tips operating at higher pressures (30–60 psi). Spray nozzles with even flat-spray tips (often designated E) are designed for band spraying where uniform distribution is desired over a zone 8–14

in. wide; they are generally used for herbicides.

Flood-type nozzle tips are generally used for complete fertilizer, liquid nitrogen, and so on, and sometimes for spraying herbicides onto the soil surface prior to incorporation. They are less suited for spraying postemergence herbicides or for applying fungicides or insecticides to plant foliage. Coverage of the target is often less uniform and complete when flood-type nozzles are used, compared with the coverage obtained with other types of nozzles. Place flood-type nozzles a maximum of 20 in. apart, rather than the standard 40-in. spacing, for better coverage. This results in an overlapping spray pattern. Spray at the maximum pressure recommended for the nozzle.

Wide-spray angle tips with full or hollow cone patterns are usually used for fungicides and insecticides. They are used at higher water volume and spray pressures than are commonly recommended for herbicide application with flat fan or flood-type nozzle tips.

9. Consider the relationship of pH and pesticides. Unsatisfactory results with some pesticides may be related to the pH of the mixing water. Some materials carry a label cautioning the user against mixing the pesticide with alkaline materials because they undergo a chemical reaction known as alkaline hydrolysis. This reaction occurs when the pesticide is mixed in water with a pH greater than 7. Many manufacturers provide information on the rate at which their product hydrolyzes. The rate is expressed as half-life, meaning the time it takes for 50% hydrolysis or breakdown to occur. Check the pH of the water. If acidification is necessary, use one of the several commercial nutrient buffer materials available on the market.

Adapted from Commercial Vegetable Production Recommendations, Pennsylvania, Delaware, Maryland, Virginia, and New Jersey (2005), http://hortweb.cas.psu.edu/extension/images/PA%2005%20Commercial%20Veg%20Recommends.pdf.

SPRAY ADJUVANTS OR ADDITIVES

Adjuvants are chemicals that, when added to a liquid spray, make it mix, wet, spread, stick, or penetrate better. Water is almost a universal diluent for pesticide sprays. However, water is not compatible with oily pesticides, and an *emulsifier* may be needed in order to obtain good mixing. Furthermore, water from sprays often remains as large droplets on leaf surfaces. A *wetting agent* lowers the interfacial tension between the spray droplet and the leaf surface and thus moistens the leaf. Spreaders are closely related to wetters and help build a deposit on the leaf and improve

weatherability. *Stickers* cause pesticides to adhere to the sprayed surface and are often called spray-stickers. They are oily and serve to increase the amounts of suspended solids held on the leaves or fruits by holding the particles in a resin-like film. *Extenders* form a sticky, elastic film that holds the pesticide on the leaves and thus reduces the rate of loss caused by sunlight and rainfall.

There are a number of adjuvants on the market. Read the label not only for dosages but also for crop uses and compatibilities, because some adjuvants must not be used with certain pesticides. Although many formulations of pesticides contain adequate adjuvants, some do require additions on certain crops, especially cabbage, cauliflower, onion, and pepper.

Spray adjuvants for use with herbicides often serve a function distinct from that of adjuvants used with insecticides and fungicides. For example, adjuvants such as oils used with atrazine greatly improve penetration of the chemical into crop and weed leaves, rather than just give more uniform coverage. Do not use any adjuvant with herbicides unless there are specific recommendations for its use. Plant damage or even crop residues can result from using an adjuvant that is not recommended.

Resources

- J. Witt, Agricultural Spray Adjuvants (Cornell University Pest Management Educational Program), http://pmep.cce.cornell.edu/facts-slides-self/facts/gen-peapp-adjuvants.html
- B. Young, Compendium of Herbicide Adjuvants, 7th ed. (Southern Illinois University, 2004), http://www.herbicide-adjuvants.com/index-7th-edition.html.

06 VEGETABLE SEED TREATMENTS

Various vegetable seed treatments prevent early infection by seedborne diseases, protect the seed from infection by soil microorganisms, and guard against a poor crop stand or crop failure caused by attacks on seeds by soil insects. Commercial seed is often supplied with the appropriate treatment.

Two general categories of vegetable seed treatments are used. *Eradication treatments* kill disease-causing agents on or within the seed, whereas *protective treatments* are applied to the surface of the seed to protect against seed decay, damping off, and soil insects. Hot-water treatment is the principal means of eradication, and chemical treatments usually serve as protectants. Follow time-temperature directions precisely for hot-water treatment and label directions for chemical treatment. When insecticides are used, seeds should also be treated with a fungicide.

HOT-WATER TREATMENT

To treat seeds with hot water, fill cheesecloth bags half full, wet seed and bag with warm water, and treat at exact time and temperature while stirring to maintain a uniform temperature. Use an accurate thermometer.

TABLE 6.12. HOT-WATER TREATMENT OF SEEDS

| Seed | $\begin{array}{c} \text{Temperature} \\ (^{\circ}F) \end{array}$ | Time (min) | Diseases Controlled |
|---|--|---------------|---|
| Broccoli, cauliflower, collards, kale, kohlrabi, turnip | 122 | 20 | Alternaria, blackleg, black rot |
| Brussels sprouts, | 122 | 25 | Alternaria, blackleg, black rot |
| Celery | 118 | 30 | Early blight, late blight |
| Eggplant | 122 | 30 | Phomopsis blight, anthracnose |
| Pepper | 122 | 25 | Bacterial spot, rhizoctonia |
| Tomato | 122 | 25 | Bacterial canker, bacterial spot, bacterial speck |
| | 132 | 30 | Anthracnose |

CHEMICAL SEED TREATMENTS

Several fungicides are commonly used for treating vegetable seed. They protect against fungal attack during the germination process, resulting in more uniform plant stands. Seed protectants are most effective under cool germination conditions in a greenhouse or field, when germination is likely to be slow, and where germinating seeds might be exposed to disease-causing organisms. Seed treatments are applied as a dust or slurry and, when dry, can be dusty. To reduce dust, the fungicide-treated seed can be covered by a thin polymer film; many seed companies offer film-coated seeds. Large-seeded vegetables may require treatment with a labeled insecticide as well as a fungicide. Always follow label directions when pesticides are used.

Certain bacterial diseases on the seed surface can be controlled by other chemical treatments:

- 1. $Tomato\ bacterial\ canker$. Soak seeds in 1.05% sodium hypochlorite solution for 20–40 min or 5% hydrochloric acid for 5–10 hr. Rinse and dry.
- Tomato bacterial spot. Soak seeds in 1.3% sodium hypochlorite for 1 min. Rinse and dry.
- 3. Pepper bacterial spot. Soak seeds in 1.3% sodium hypochlorite for 1 min. Rinse and dry.

DO NOT USE CHEMICALLY TREATED SEED FOR FOOD OR FEED.

Adapted from A. F. Sherf and A. A. MacNab, Vegetable Diseases and Their Control, Wiley, New York (1986).

Additional References for Seed Treatment

- M. McGrath, Treatments for Managing Bacterial Pathogens in Vegetable Seed (2005), http://vegetablemdonline.ppath.cornell.edu/ NewsArticles/All_BactSeed.htm
- J. Boucher and J. Nixon, Preventing Bacterial Diseases of Vegetables with Hot-water Seed Treatment, University of Connecticut Cooperative Extension Service; and R. Hazard and R. Wick (University of Massachusetts Cooperative Extension Service), http://www.hort.uconn.edu/ipm/homegrnd/htms/54sedtrt.htm
- S. Miller and M. Lewis Ivey, Hot Water and Chlorine Treatment of Vegetable Seeds to Eradicate Bacterial Plant Pathogens (Cooperative Extension Service, Ohio State University), http://ohioline.osu.edu/hyg-fact/3000/3085.html

ORGANIC SEED TREATMENTS

With the increasing interest in organic vegetables, the need for information about organic seed production, sources, and treatment is greater. Seed quality and vigor are important aspects for high-quality organic seeds. The seed industry is working to provide vegetable seeds that meet the requirements for organic crop production. Likewise, the seed treatment technology for organic seeds is increasing in scope—for example, seed coating and treatment to increase germination uniformity and adaptation to mechanized seeding, among other needs. The following lists a few publications that address organic seed quality and seed treatment:

- J. Bonina and D. J. Cantliffe, Seed Production and Seed Sources of Organic Vegetables (University of Florida Cooperative Extension Service), http://edis.ifas.ufl.edu/hs227
- S. Koike, R. Smith, and E. Brennan, *Investigation of Organic Seed Treatments for Spinach Disease Control*, http://vric.ucdavis.edu/scrp/sum-koike.html

07 NEMATODES

PLANT PARASITIC NEMATODES

Nematodes are unsegmented round worms that range in size from microscopic to many inches long. Some nematodes, usually those that are microscopic or barely visible without magnification, attack vegetable crops and cause maladies, restrict yields, or, in severe cases, lead to total crop failure. Many kinds of nematode are known to infest the roots and aboveground plant parts of vegetable crops. Their common names are usually descriptive of the affected plant part and the resulting injury.

TABLE 6.13. COMMONLY OBSERVED NEMATODES IN VEGETABLE CROPS

| Common Name | Scientific Name |
|-----------------------|--|
| A. 1 1. | D.I. I. |
| Awl nematode | $Dolichodorus \ { m spp}.$ |
| Bud and leaf nematode | $Aphelenchoides \ { m spp}.$ |
| Cyst nematode | Heterodera spp. |
| Dagger nematode | Xiphinema spp. |
| Lance nematode | $Hopolaimus \ { m spp}.$ |
| Root-lesion nematode | Pratylenchus spp. |
| Root-knot nematode | $Meloidogyne \ { m spp}.$ |
| Spiral nematode | Helicotylenchus spp. and Scutellonema spp. |
| Sting nematode | $Belonolaimus \ { m spp.}$ |
| Stubby-root nematode | Trichodorus spp. |
| Stunt nematode | Tylenchorhynchus spp. |
| - | |

Nematodes are most troublesome in areas with mild winters where soils are not subject to freezing and thawing. Management practices and chemical control are both required to keep nematode numbers low enough to permit normal plant growth where populations are not kept in check naturally by severe winters.

The first and most obvious control for nematodes is avoiding their introduction into uninfected fields or areas. This may be done by quarantine over large geographical areas or by means of good sanitation in smaller areas. A soil sample for a nematode assay through the County Extension Service can provide information on which nematodes are present and their population levels. This information is valuable for planning a nematode management program.

Once nematodes have been introduced into a field, several management practices help control them: rotating with crops that a particular species of nematode does not attack, frequent disking during hot weather, and alternating flooding and drying cycles.

If soil management practices are not possible or are ineffective, chemicals (nematicides) may have to be used to control nematodes. Some fumigants are effective against soilborne disease, insects, and weed seeds; these are termed *multipurpose soil fumigants*. Growers should select a chemical for use against the primary problem to be controlled and use it according to label directions.

TABLE 6.14. PLANT PARASITIC NEMATODES KNOWN TO BE OF ECONOMIC IMPORTANCE TO VEGETABLES

| ggplant | \times \times | |
|---|---|--|
| Pepper 1 | \times \times | |
| Tomato | \times | |
| Sweet Sweet Corn Potato | × | |
| Sweet | $\times \times \times \times \times$ | |
| Potato | \times \times | |
| Onion | \times | |
| Okra | \bowtie | |
| Leaf Crops | \times \times | |
| Cucurbits | ×× | |
| Crucifers | \bowtie | |
| Celery | $\times \times \times$ | |
| Carrot | \bowtie | |
| Bean and Peas | $\times \times \times \times \times$ | |
| Bean Leaf Sweet Sweet And Nematode Peas Carrot Celery Crucifers Cucurbits Crops Okra Onion Potato Corn Potato Tomato Pepper Eggplant | Sting Stubby root Root lesion Cyst Awl Stunt Lance Spiral Ring Dagger Bud and leaf Reniform | |

From J. Noling, "Nematodes and Their Management," in S. M. Olson and E. H. Simonne (eds.), Vegetable Production Handbook for Florida (Florida Cooperative Extension Service, 2005–2006), http://edis.ifas.ufl.edu/CV112.

MANAGEMENT TECHNIQUES FOR CONTROLLING NEMATODES

- 1. Crop rotation. Exposing a nematode population to an unsuitable host crop is an effective means of reducing nematodes in a field. Cover crops should be established rapidly and kept weed free. There are many cover crop options, but growers must consider the species of nematode in question and how long the alternate crop is needed. Also, certain cover crops may be effective as non-hosts for nematodes but may not fit into a particular cropping sequence.
- Fallowing. Practicing clean fallowing in the intercropping season is
 probably the single most effective nonchemical means to reducing
 nematode populations. Clean disking of the field must be practiced
 frequently to keep weeds controlled because certain nematodes can
 survive on weeds.
- 3. Plant resistance. Certain varieties have genetic resistance to nematode damage. Where possible, these varieties should be selected when their other horticultural traits are acceptable. There are nematode-resistant varieties in tomato and pepper.
- 4. Soil amendments. Certain soil amendments, such as compost, manures, cover crops, chitin, and other materials, have been shown to reduce nematode populations. The age of the material, amount applied, and level of incorporation affect performance.
- 5. *Flooding*. Extended periods of flooding can reduce nematode populations. This technique should be practiced only where flooding is approved by environmental agencies. Alternating periods of flooding and drying seems to be more effective than a single flooding event.
- 6. Soil solarization. Nematodes can be killed by elevated heat created in the soil by covering it with clear polyethylene film for extended periods. Solarization works best in clear, hot, and dry climates. More information on solarization can be found on pages 317–319.
- Crop management. Growers should rapidly destroy and till crops that
 are infested with nematodes. Irrigation water should not drain from
 infested fields to noninfested fields, and equipment should be cleaned
 between infested and clean fields.
- 8. Chemical control. Some fumigant and nonfumigant nematicides are approved for use against nematodes, but not all vegetable crops have nematicides recommended for use. Effectiveness of the treatment depends on many factors, including timing, placement in the soil, soil moisture, soil temperature, soil type, and presence of plastic mulch. Growers should refer to their state Extension recommendations for the approved chemicals for particular crops.

Adapted from J. Noling, "Nematodes and Their Management," in S. M. Olson and E. H. Simonne (eds.), Vegetable Production Handbook for Florida (Florida Cooperative Extension Service, 2005–2006), http://edis.ifas.ufl.edu/CV112.

08 DISEASES

GENERAL DISEASE CONTROL PROGRAM

Diseases of vegetable crops are caused by fungi, bacteria, viruses, and mycoplasms. For a disease to occur, organisms must be transported to a susceptible host plant. This may be done by infected seeds or plant material, contaminated soil, wind, water, animals (including humans), or insects. Suitable environmental conditions must be present for the organism to infect and thrive on the crop plant. Effective disease control requires knowledge of the disease life cycle, time of likely infection, agent of distribution, plant part affected, and the symptoms produced by the disease.

- *Crop rotation:* Root-infecting diseases are the usual targets of crop rotation, although rotation can help reduce innocula of leaf- and stem-infecting organisms. Land availability and costs are making rotation challenging, but a well-planned rotation program is still an important part of an effective disease control program.
- Site selection: Consider using fields that are free of volunteer crops and perimeter weeds that may harbor disease organisms. If aerial applications of fungicides are to be used, try to select fields that are geometrically adapted to serial spraying (long and wide), are away from homes, and have no bordering trees or power lines.
- Deep plowing: Use tillage equipment such as plows to completely bury plant debris in order to fully decompose plant material and kill disease organisms.
- Weed control: Certain weeds, particularly those botanically related to the crop, may harbor disease agents, especially viruses, that could move to the crop. Also, weeds within the crop could harbor diseases and by their physical presence interfere with deposition of fungicides on the crop. Volunteer plants from previous crops should be carefully controlled in nearby fallow fields.
- Resistant varieties: Where possible, growers should choose varieties that carry genetic resistance to disease. Varieties with disease resistance require less pesticide application.
- Seed protection: Seeds can be treated with fungicides to offer some degree of protection of the young seedling against disease attack. Seeds planted in warm soil germinate fast and possibly can outgrow disease development.

- Healthy transplants: Growers should always purchase or grow disease-free transplants. Growers should contract with good transplant growers and should inspect their transplants before having them shipped to the farm. Paying a little extra to a reputable transplant producer is good insurance.
- Field observation: Check fields periodically for disease development by walking the field and inspecting the plants up close, not from behind the windshield. Have any suspicious situations diagnosed by a competent disease diagnosis laboratory.
- Foliar fungicides: Plant disease outbreaks sometimes can be prevented or minimized by timely use of fungicides. For some diseases, it is essential to have a preventative protectant fungicide program in place. For successful fungicide control, growers should consider proper chemical selection, use well-calibrated sprayers, use correct application rate, and follow all safety recommendations for spray application.
- Integrated approach: Successful vegetable growers use a combination of these strategies or the entire set of strategies listed above. Routine implementation of combinations of strategies is needed where a grower desires to reduce the use of fungicides on vegetable crops.

COMMON VEGETABLE DISEASES

Some of the more common vegetable diseases are described below. Consult your local County Extension Service for recommendations for specific fungicide information, as products and use recommendations change frequently. When using fungicides, read the label and carefully follow the instructions. Do not exceed maximum rates given, observe the interval between application and harvest, and apply only to those crops for which use is approved. Make a record of the product used, trade name, concentration of the fungicide, dilution, rate applied per acre, and dates of application. Follow local recommendations for efficacy and read the directions on the label for proper use.

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| Crop | Disease | Description | Control |
|-----------|----------------------|--|--|
| Asparagus | Fusarium root rot | Fusarium root Damping off of seedlings. Yellowing, stunting, or wilting of the growing stalks; vacually bundle discoloration. Crown | n |
| | Rust | death gives helds a spotty appearance. Reddish or black pustules on stems and foliage | planting. Cut and burn diseased tops. Use resistant |
| Bean | Anthracnose | Brown or black sunken spots with pink centers on pods, dark red or black cankers on stems and leaf veins. | Use disease-free seed and rotate crops every 2 years. Plow stubble. Do not cultivate when plants are wet. Use |
| | Bacterial blight | Large, dry, brown spots on leaves, often encircled by yellow border; water-soaked spots on pods; reddish cankers on stems. Plants may be gridled. | approved imgrances. Use disease-free seed. Do not cultivate when plants are wet. Use 3-year rotation. Use approved fungicides. |
| | Mosaic (several) | Mottled (light and dark green) and curled leaves; stunting, reduced yields. | Use mosaic-resistant varieties. Control weeds in areas adjacent to field. Control insect (aphid, white fly) carrier with insortiones |
| | Powdery mildew | Faint, slightly discolored spots appear first on leaves, later on stems and pods, from which white powdery spots develop and may cover the entire plant. | Use approved fungicides. |

| Use approved fungicides. | Crop rotation. Treat seed with approved fungicides. | Use approved fungicides. | Long rotation. Use approved fungicides. | Seed decay in soil; young seedlings collapse Avoid wet soils, rotate crops. Treat seed and die. | n | Use approved fungicides. | Use hot-water-treated seed and long of rotation. Sanitation. |
|--|--|--|---|---|---|--|---|
| Red to black pustules on leaves; leaves vellow and drop. | Seed or seedling decay, which results in poor stands. Occurs most commonly in cold, wet soils. | Water-soaked spots on plants. White, cottony masses on pods. | Numerous light tan to brown spots with reddish to dark brown borders on leaves. | Seed decay in soil; young seedlings collaps and die. | Lighter than normal leaf spots on upper surface and white mildew areas on lower side. Roots, leaves, flowers, and seed balls distorted on stecklings. | Alternaria leaf Damping off of seedlings. Small, circular spot yellow areas that enlarge in concentric circles and become black and sooty. | Sunken areas on stem near ground line resulting in girdling; gray spots speckled with black dots on leaves and stems. |
| Rust | Seed rot | White mold | Cercospora | Damping off | Downy mildew | Alternaria leaf spot | Black leg |
| | | | Beet | | | Broccoli, Brussels sprouts, cabbage, cauliflower, kale, | |

TABLE 6.15. DISEASE CONTROL FOR VEGETABLES (Continued)

| Crop | Disease | Description | Control |
|--|---------------------------|--|--|
| | Black rot | Yellowing and browning of the foliage; blackened veins; stems show blackened | Use hot-water-treated seed and long rotation. Do not work wet fields. |
| | Club root | ring when cross-sectioned. Yellow leaves or green leaves that wilt on hot days; large, irregular swellings or clubs on roots. | Start plants in new, steamed, or fumigated plant beds. Adjust soil pH to 7.2 with hydrated lime before planting. |
| | Downy mildew | Downy mildew Begins as slight yellowing on upper side of leaves; white mildew on lower side; spots enlarge until plant dies. | Use approved fungicides. |
| | Fusarium vellows | Yellowish green leaves; stunted plants; lower leaves drop. | Use yellows-resistant varieties. |
| $\begin{array}{c} \text{Cantaloupe} \\ (See \text{ Vine} \\ \text{Crops}) \end{array}$ | , | • | |
| Carrot | Alternaria leaf blight | Small, brown to black, irregular spots with yellow margins may enlarge to infect the entire ton. | Use approved fungicides. |
| | Cercospora leaf blight | Small, necrotic spots that may enlarge and infect the entire too. | Use approved fungicides. |
| | Aster Yellows | Purpling of tops; yellowed young leaves at center of crown followed by bushiness | Control leafhopper carrier with insecticides. |
| | | due to excessive petiole formation. Roots become woody and form numerous adventitious roots. | |

| Celery | Aster yellows | Yellowed leaves; stunting; tissues brittle and bitter in taste. | Use resistant varieties. Control leafhopper carrier with insecticides. Control weeds in adjacent areas. |
|--|-----------------------------|--|---|
| | Bacterial blight | Bright yellow leaf spots, center turns brown, and a yellow halo appears with enlargement. | Seedbed sanitation. Copper compounds. |
| | Early blight Late blight | Dead, ash gray, velvety areas on leaves. Yellow spots on old leaves and stalks that turn dark gray speckled with black dots. | Use approved fungicides. Use approved fungicides. |
| | Mosaic | Dwarfed plants with narrow, gray, or mottled leaves. | Control weeds in adjacent areas. Control aphid carrier with insecticides. |
| | Pink rot | Water-soaked spots; white- to pink-colored cottony growth at base of stalk leads to rotting. | Crop rotation. Flooding for 4–8 weeks. Use approved fungicides. |
| $\begin{array}{c} \text{Cucumber} \\ (See \text{ Vine} \\ \text{Crops}) \end{array}$ | | | |
| Eggplant | Anthracnose | Sunken, tan fruit lesions. | Use disease-free seed. Use approved fungicides. |
| | Phomopsis blight | Young plants blacken and die; older plants have brown spots on leaves and fruit covered with brownish black pustules. | Use resistant varieties. Use approved fungicides. |
| | Verticillium wilt | Slow wilting; browning between leaf veins; stunting. | Fumigate soil with approved fumigants. Use verticillium-tolerant varieties. Use long rotation. |
| Endive, escarole, lettuce | Aster yellows | Center leaves bleached, dwarfed, curled, or twisted. Heads do not form; young plants particularly affected. | Control leafhopper carrier with insecticides. |

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| Crop | Disease | Description | Control |
|-----------|--|---|---|
| | Big vein | Leaves with light green, enlarged veins developing into yellow, crinkled leaves; | Avoid cold, wet soils. Use tolerant varieties. Crop rotation. |
| | Bottom rot | Damage begins at base of plants; blades of leaves rot first, then the midrib, but the main stem is hardly affected | Avoid wet, poorly drained areas. Plant on raised beds. Practice 3-year rotation. |
| | Downy mildew | Light green spots on upperside of leaves; lesions enlarge and white mycelium appears on opposite side of spots; hroming and dwarfing of plant | Use approved fungicides. |
| | Drop | Wilting of outer leaves; watery decay on stems and old leaves | Crop rotation. Deep plowing. Raised beds. Use annroved funcicides |
| | Mosaic | Mottling (yellow and green), ruffling, or distortion of leaves; plants have unthriffy | Use virus-free MTO seed. Plant away from old lettuce beds. Control weeds. |
| | Tipburn | appearance. Edges of tender leaves brown and die; may interfere with growth; most severe on head lettuce. | Use tolerant varieties. Prevent stress by providing good growing conditions. |
| Lima bean | Downy mildew | Purpling and distortion of leaf veins; white downy mold on pods; blackened beans. | Use resistant varieties and disease-free seed. Use approved funcioides. |
| Okra | Southern blight Verticillium wilt | Mass of pinkish funds bodies around base of plant; sudden loss of leaves. Stunting; chlorosis; shedding of leaves. | Crop rotation. Deep plowing of plant stubble. Crop rotation. Avoid planting where disease was previously present. |

| Use approved fungicides. | Use approved fungicides. | Undercut and windrow plants until inside neck tissues are dry before storage. Cure at 93–95°F for 5 days. | Avoid infected soils. Use tolerant varieties. | Use approved fungicides. | Crop rotation. Use approved fungicides. | lidge soil over shoulders. | Practice 2-year rotation; use well-drained soil with pH 7.0. | Use disease-free seed and resistant varieties. Use approved fungicides. |
|--|--|--|--|-------------------------------|---|--|---|---|
| Papery spots on leaves; browning and death of upper portion of leaves; delayed maturity. | Begins as pale green spot near tip of leaf; C purple mold found when moisture present; infected leaves olive-green to black. | Soft, brownish tissue around neck; scales around neck are dry, and black sclerotia may form. Essentially a dry rot if soft rot bacteria not present. | n seedling stage ife cycle. Affected vel. and die. | urple seed 3–4 tses. | velop on ooty powder | Brown discoloration near shoulder or crown Ridge soil over shoulders. of root. | Leaves and petioles turn yellow and then F brown. Entire plant may be killed. | White, powdery mold on leaves, stems, and L pods; affected areas become brown and necrotic. |
| Blight (blast) | Downy mildew | Neck rot | Pink rot | Purple blotch | Smut | Canker | Leaf blight | Powdery mildew |
| Onion | | | | | | Parsnip | | Pea |

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| Crop | Disease | Description | Control |
|-----------------------|------------------------|---|--|
| | Root rot | Rotted and yellowish brown or black stems (below ground) and roots; outer layers of | Early planting and 3-year rotation. Do not double-crop with bean. Seed |
| | Virus | root slough off, leaving a central core. Several viruses affect pea, causing mottling, distortion of leaves, rosetting, | treatment. Use resistant varieties. Control aphid carrier with insecticides. |
| | Wilt | chlorosis, or necrosis. Yellowing leaves; dwarfing, browning of xylem; wilting. | Early planting and 3-year rotation. Use resistant varieties. |
| Pepper | Anthracnose | Dark, round spots with black specks on fruits. | Use approved fungicides. |
| | Bacterial leaf spot | Yellowish green spots on young leaves; raised, brown spots on undersides of older leaves; brown, cracked, rough spots on fruit; old leaves turn vellow. | Use disease-free seed, hot-water-treated seed. Use approved bactericides. Use resistant varieties. |
| | Mosaic | Mottled (yellowed and green) and curled leaves; fruits yellow or show green ring spots; stunted; reduced vields. | Use resistant varieties. Control insect carriers (particularly aphids) and weed hosts. Use stylet oil. |
| Potato | Early blight | Dark brown spots on leaves; foliage injured; reduced yields. | Bury all cull potatoes. Use approved fungicides. |
| | Late blight | Dark, then necrotic area on leaves and stem; infected tubers rot in storage. Disease is favored by moist conditions. | Bury cull piles. Use approved fungicides. |

| | Rhizoctonia | Necrotic spots, girdling and death of sprouts before or shortly after emergence. Brown to black raised spots on mature tubers | Avoid deep planting to encourage early emergence. Use disease-free seed. Use approved fungicides. |
|-----------------|---------------|--|---|
| | Scab | Rough, scabby, raised, or pitted lesions on tubers. | Crop rotation. Use resistant varieties. Maintain soil pH about 5.3. |
| | Virus | A large number of viruses infect potato, causing leaf mottling, distortion, and dwarfing. Some viruses cause irregularly | Use certified seed. Control aphid and leafhopper carriers with insecticides. |
| iish | Downy mildew | shaped or necrotic area in tubers. Internal discoloration of root crown tissue. Outer surface may become dark and rough at the soil line. | Select clean, well-drained soils. Use approved fungicides. |
| | Fusarium wilt | Young plants yellow and die rapidly in warm weather. Stunting, unilateral leaf yellowing; vascular discoloration of fleshy mores | Use tolerant varieties. Avoid infested soil. |
| ıbarb | Crown rot | Wilting of leaf blades; browning at base of leaf stalk leading to decay. | Plant in well-drained soil. |
| | Leaf spot | Tiny, greenish yellow spots (resembling mosaic) on upper side of leaf, eventually browning and forming a white spot surrounded by a red band; these spots may drop out to give a shot-hole | Use approved fungicides. |
| abaga, ırnip | Alternaria | appearance. Small, circular, yellow areas that enlarge in concentric circles and become a black sooty color. Roots may become infested in storage. | Use hot-water-treated seed. Use approved fungicides. |

| | Control | Use approved fungicides. |
|--|-------------|---|
| TABLE 6.15. DISEASE CONTROL FOR VEGETABLES (Continued) | Description | Small, water-soaked spots on all above- ground parts, which become light-colored |
| DISEASE CO | Disease | Anthracnose |
| TABLE 6.15. | Crop | |

| | Anthracnose | Small, water-soaked spots on all above- ground parts, which become light-colored and may drop out. Small, sunken, dry | Use approved fungicides. |
|--------------|----------------------------|---|---|
| | Club root | spots on turnip roots, which are subject to secondary decay. Tumor-like swellings on tap root. Main root Avoid soil previously infested with club may be distorted. Diseased roots decay root. Adjust acid soil to pH 7.3 by | Avoid soil previously infested with club root. Adjust acid soil to pH 7.3 by |
| | Downy mildew | prematurely. Small, purplish, irregular spots on leaves, stems, and seedpods that produce fluffy white growth. Desiccation of roots in | liming. Use approved fungicides. |
| | Mosaic virus | storage. Stunted plants having ruffled leaves. Infected notes store nowly | Destroy volunteer plants. Control aphid |
| Southern pea | Southern pea Fusarium wilt | Yellowed leaves; wilted plants; interior of stems lemon vellow | Avoid infested soil. |
| Spinach | Blight (CMV) | aves; stunted plants; | Use tolerant varieties. Control aphid carrier with insecticides |
| | Downy mildew | Ķ | Use resistant varieties. Use approved fungicides. |
| Compate (Co. | | ,) |) |

Squash (See Vine Crops)

| Use disease-free plants and resistant varieties. Use approved fungicides. | Use less susceptible varieties. Use approved fungicides. | Use disease-free plants and resistant varieties. Renew perennial plantings frequently. Use approved functicides. | Use disease-free plants and resistant varieties. Use approved fungicides. | Use resistant varieties. Use approved fungicides. | Improve drainage and avoid compaction of soil. Use disease-free plants and resistant varieties | Preplant soil fumigation. Use resistant varieties. | Use resistant varieties. Control corn flea beetle with insecticides. | Use resistant varieties. Use approved fungicides. | Use tolerant varieties. Plant tolerant varieties around susceptible ones. Control aphid carrier with insecticides. | Use seed treated with approved fungicides. |
|---|--|--|--|---|--|---|---|---|--|--|
| Spotting and girdling of stolens and petioles, crown rot, fruit rot, and a black leaf spot; commonly occurs in southeastern United States | Rot on green or ripe fruit, beginning at calyx or contact with infected fruit; affected area supports white or gray mycelium | Numerous irregular, purplish blotches with brown centers; entire leaves dry up and appear scorched. | Indefinite-shaped spots with brown, gray, or white centers and purple borders. | Characteristic white mycelium on leaves, flower, and fruit. | Stunted plants having roots with red stele seen when root is cut lengthwise. | Marginal and interveinal necrosis of outer leaves: inner leaves remain green. | Dwarfing; premature tassels die; yellow bacterial slime oozes from wet stalks; stem dries and dies. | Canoe-shaped spots on leaves. | Stunting; mottling of new leaves in whorl and poor ear fill at the base. | Seed decays in soils. |
| Anthracnose | Gray mold | Leaf scorch | Leaf spot | Powdery mildew | Red stele | Verticillium | Bacterial blight | Leaf blight | Maize dwarf mosaic | Seed rot |
| Strawberry | | | | | | | Sweet corn | | | |

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| Crop | Disease | Description | Control |
|------------------------|---------------|---|--|
| | Smut | Large, smooth, white galls, or outgrowths on ears, tassels, and nodes; covering dries and breaks open to release black, | Use tolerant varieties. Control corn borers with insecticides. |
| Sweet potato Black rot | Black rot | powdery, or greasy spores. Black depressions on sweet potato; black cankers on underground stem parts. | Select disease-free potato seed. Rotate crops and planting beds. Use vine cuttings for propagation rather than |
| | Internal cork | ssions in h urple | slips. Select disease-free seed potatoes. |
| | Pox | borders on new growth of leaves. Plants dwarfed; only one or two vines produced; leaves thin and pale green; soil | Use disease-free stock and clean planting beds. Sulfur to lower soil pH to 5.2. |
| | Scurf | rot pits on roots. Brown to black discoloration of root; uniform rusting of root surface. | Rotation of crops and beds. Use disease- free stock. Use vine cuttings rather |
| | Stem rot | Yellowing between veins; vines wilt; stems | Select disease-free seed potatoes. Rotate |
| Tomato | Anthracnose | Begins with circular, sunken spots on fruit, as spots enlarge, center becomes dark and fruit rots. | Use approved fungicides. |

| Bacterial | Wilting: rolling, and browning of leaves: | Use hot-water-treated seed. Avoid |
|----------------|--|--|
| canker | pith may discolor or disappear; fruit displays bird's-eye spots. | planting in infested fields for 3 years. |
| Bacterial spot | Young lesions on fruit appear as dark, raised spots; older lesions blacken and | Use hot-water-treated seed. Use approved bactericides. |
| | appear sunken with brown centers; leaves brown and dry. | |
| Early blight | Dark brown spots on leaves; brown cankers Use approved fungicides. on stems; girdling; dark, leathery, | Use approved fungicides. |
| | decayed areas at stem end of fruit. | |
| Late blight | Dark, water-soaked spots on leaves; white | Use approved fungicides. |
| | fungus on undersides of leaves; withering | |
| | of leaves; water-soaked spots on fruit | |
| | turn brown. Disease is favored by moist | |
| | conditions. | |
| Fusarium wilt | Yellowing and wilting of lower, older leaves; Use resistant varieties. | Use resistant varieties. |
| | disease eventually affects whole plant. | |
| Gray leaf spot | Symptoms appear first in seedlings. Small | Use resistant varieties. Use approved |
| | brown to black spots on leaves, which | fungicides. |
| | enlarge and have shiny gray centers. The | |
| | centers may drop out to give shotgun | |
| | appearance. Oldest leaves affected first. | |
| Leaf mold | Chlorotic spots on upper side of oldest | Use resistant varieties. Stake and prune |
| | leaves appear in humid weather. | to provide air movement. Use approved |
| | Underside of leaf spot may have green | fungicides. |
| | mold. Spots may merge until entire leaf | |
| | is affected. Disease advances to younger | |
| | leaves. | |

TABLE 6.15. DISEASE CONTROL FOR VEGETABLES (Continued)

| Crop | Disease | Description | Control |
|---|-------------------------|--|---|
| | Mosaic | Mottling (yellow and green) and roughening of leaves; dwarfing; reduced yields: russeting of fruit. | Avoid contact by smokers. Control aphid carrier with insecticides. Stylet oil may be effective. |
| | Tomato spotted wilt | Brown spots, some circular on youngest leaves, stunted plant. Fruits misshapen | Use a combination of resistant varieties, highly reflective mulch to repel the |
| | virus | often with circular brown rings, a diagnostic characteristic of this disease. | silverleaf white fly, and plant activators. |
| | Verticillium wilt | Differs from fusarium wilt by appearance of disease on all branches at the same | Use resistant varieties. |
| | | time; yellow areas on leaves become brown; midday wilting; dropping of leaves beginning at bottom. | |
| Vine Crops: cantaloupe, cucumber, | Alternaria leaf spot | Ci | Field sanitation. Use disease-free seed. Use approved fungicides. |
| pumpkin, squash, watermelon | Angular leaf spot | Irregular, angular, water-soaked spots on leaves that later turn gray and die. Dead tissue may tear away, leaving holes. Nearly circular fruit spots, which become white. | Use tolerant varieties. Use approved bactericides. |

| Use tolerant varieties. Use approved fungicides. | Control striped cucumber beetles with insecticides. Remove wilting plants from field. | Use disease-free seed. Crop rotation. Cure fruit for storage at 85°F for 2 weeks, store at 50–55°F. Use approved fungicides. | Use tolerant varieties. Use approved fungicides. | Use resistant varieties. Avoid infested soils. | Use disease-free seed. Rotate crops. Use approved fungicides. | Control striped cucumber beetle or aphid with insecticides. Use resistant varieties. Destroy surrounding perennial weeds. |
|---|---|---|---|---|--|---|
| Reddish black spots on leaves; elongated tan cankers on stems; fruits have sunken spots with flesh-colored ooze in center, later turning black. | Vines wilt and die; stem sap produces strings; no yellowing occurs. | Water-soaked areas appear on rinds of fruit in storage. Brown or black infected tissue rapidly invades entire plant. | Angular, yellow spots on older leaves; purple fungus on undersides of leaves when moisture present; leaves wither, die; fruit may be dwarfed, with poor flavor. | Stunting and yellowing of vine; watersoaked streak on one side of vine eventually turns yellow, cracks, and | Lesions may occur on stems, leaves, and fruit from which a reddish gummy exudate may ooze. | Mottling (yellow and green) and curling of leaves; mottled and warty fruit; reduced yields; burning and dwarfing of entire plant. |
| Anthracnose | Bacterial wilt | Black rot (squash and pumpkin only) | Downy mildew | Fusarium wilt | Gummy stem blight | Mosaic (several) |

TABLE 6.15. DISEASE CONTROL FOR VEGETABLES (Continued)

| Control | Use tolerant varieties. Use approved fungicides. Use resistant varieties. Use approved fungicides. Little control, except to avoid planting under high whitefly populations and use tolerant varieties. |
|-------------|--|
| Description | White, powdery growth on upper leaf surface and petioles; wilting of foliage. Water-soaked spots on leaves turning white; sunken cavity on fruit later covered by grayish olive fungus; fruit destroyed by soft rot. Silvering or white coloration to leaves. Associated with silverleaf whitefly feeding, disorder is worse in fall crops in southern United States. |
| Disease | Powdery mildew Cucumber scab Squash silverleaf |
| Crop | |

DISEASE IDENTIFICATION WEBSITES WITH DISEASE PHOTOGRAPHS AND DIAGNOSTIC INFORMATION

Plant disease control begins with an accurate diagnosis and identification of the disease-causing organism or agent. Although photos are helpful in identifying plant diseases, we encourage the grower to consult a knowledgeable disease expert to provide confirmation of the identification before any control strategy is implemented. Here are a few websites containing photographs and helpful diagnostic information:

Arkansas, http://www.aragriculture.org/pestmanagement/diseases/image_library/default.htm

Florida, http://edis.ifas.ufl.edu/VH045

Maryland, http://www.agnr.umd.edu/users/hgic/diagn/home.html
Minnesota, http://www.extension.umn.edu/projects/yardandgarden/
diagnostics/mainvegetables.html

New York, http://plantclinic.cornell.edu/vegetable/index.htm; http://vegetablemdonline.ppath.cornell.edu/PhotoPages/PhotoGallery.htm
Pennsylvania, http://vegdis.cas.psu.edu/Identification.html
Utah, http://extension.usu.edu/plantpath/vegetables/vegetables.htm

Washington, http://mtvernon.wsu.edu/path_team/diseasegallery.htm
Other, http://www.gardeners.com/gardening/content.asp?copy_id=5366

09 INSECTS

SOME INSECTS THAT ATTACK VEGETABLES

Most vegetable crops are attacked by insects at one time or another in the crop growth cycle. Growers should strive to minimize insect problems by employing cultural methods aimed at reducing insect populations. These tactics include using resistant varieties, reflective mulches, crop rotation for soilborne insects, destruction of weed hosts, stylet oils, insect repellants, trap crops, floating row covers, or other tactics. Sometimes insecticides must be used in an integrated approach to insect control when the economic threshold insect population is reached. When using insecticides, read the label and carefully follow the instructions. Do not exceed maximum rates given, observe the interval between application and harvest, and apply only to crops for which use is approved. Make a record of the product used, trade name, formulation, dilution, rate applied per acre, and dates of application. Read and follow all label precautions to protect the applicator and workers from insecticide injury and the environment from contamination. Follow local recommendations for efficacy and read the label for proper use.

TABLE 6.16. INSECTS THAT ATTACK VEGETABLES

| Crop | Insect | Description |
|-----------|--------------------------------------|---|
| Artichoke | Aphid | Small, green, pink, or black soft-bodied insects that rapidly reproduce to large populations. Damage results from sucking plant sap; indirectly from virus transmission to crop plants. |
| | Plume moth | Small wormlike larvae blemish bracts and may destroy the base of the bract. |
| Asparagus | Beetle and twelve- spotted beetle | Metallic blue or black beetles (1/4 in.) with yellowish wing markings and reddish, narrow head. Larvae are humpbacked, slate gray. Both feed on shoots and foliage. |
| | Cutworm | Dull-colored moths lay eggs in the soil. The produce dark- colored, smooth worms, 1–2 in. long, that characteristically curl up when disturbed. May feed below ground or above- ground at night. |
| Bean | Aphid Corn earworm | See Artichoke. Gray-brown moth (1½ in.) with dark wing tips deposits eggs, especially on fresh corn silk. Brown, green, or pink larvae (2 in.) feed on silk, kernels, and foliage. |

TABLE 6.16. INSECTS THAT ATTACK VEGETABLES (Continued)

| Crop | Insect | Description |
|------|-------------------------|--|
| | Leafhopper | Green, wedge-shaped, soft bodies (½s in.). When present in large numbers, sucking of plant sap causes plant distortion or burned appearance. Secondary damage results from transmission of yellows disease. |
| | Mexican bean beetle | Copper-colored beetle (1/4 in.) with 16 black spots on its back. Orange to yellow spiny larva (1/3 in.). Beetle and larvae feeding on leaf undersides cause a lacework appearance. |
| | Seed corn maggot | Grayish brown flies (½ in.) deposit eggs in the soil near plants. Cream-colored, wedge-shaped maggots (¼ in.) tunnel into seeds, potato seed pieces, and sprouts. |
| | Spider mite | Reddish, yellow, or greenish tiny eight-legged spiders suck plant sap from leaf undersides, causing distortion. Fine webs may be visible when mites are present in large numbers. Mites are not true insects. |
| | Spotted cucumber beetle | Yellowish, elongated beetle (1/4 in.) with 11 or 12 black spots on its back. Leaf-feeding may destroy young plants when present in large numbers. Transmits bacterial wilt of curcurbits. |

TABLE 6.16. INSECTS THAT ATTACK VEGETABLES (Continued)

| Crop | Insect | Description |
|--|--------------------------|---|
| | Striped cucumber beetle | Yellow (½ in.) with three black stripes on its back; feeds on leaves. White larvae (½ in.) feed on roots and stems. Transmits bacterial wilt of curcurbits. |
| | Tarnish plant bug | Brownish, flattened, oval bugs (1/4 in.) with a clear triangular marking at the rear. Bugs damage plants by sucking plant sap. |
| Beet | Aphid | See Artichoke. |
| | Flea beetle Leaf miner | Small (1/6 in.), variable-colored, usually dark beetles, often present in large numbers in the early part of the growing season. Feeding results in numerous small holes, giving a shotgun appearance. Indirect damage results from diseases transmitted. Tiny black and yellow adults. Yellowish white maggot-like larvae tunnel within leaves and cause white or translucent irregularly |
| | Webworm | damaged areas. Yellow to green worm (1½ in.) with a black stripe and |
| | | numerous black spots on its back. |
| Broccoli, Brussels | Aphid | See Artichoke. |
| sprouts, | Flea beetle | See Beet. |
| cabbage, cauliflower, kale, kohlrabi | Harlequin cabbage bug | Black, shield-shaped bug (% in.) with red or yellow markings. |

TABLE 6.16. INSECTS THAT ATTACK VEGETABLES (Continued)

| Crop | Insect | Description |
|--------------------------------|--------------------------|---|
| | Cabbage maggot | Housefly-like adult lays eggs in the soil at the base of plants. Yellowish, legless maggot (1/4–1/3 in.) tunnels into roots and lower stem. |
| | Cabbage looper | A brownish moth (1½ in.) that lays eggs on upper leaf surfaces. Resulting worms (1½ in.) are green with thin white lines. Easily identified by their looping movement. |
| | Diamondback moth | Small, slender gray or brown moths. The folded wings of male moths show three diamond markings. Small (½ in.) larvae with distinctive V at rear, wiggle when disturbed. |
| | Imported cabbage worm | White butterflies with black wing spots lay eggs on undersides of leaves. Resulting worms (1½ in.) are sleek, velvety, green. |
| Cantaloupe (See Vine Crops) | | |
| Carrot | Leafhopper Rust fly | See Bean. Shiny, dark fly with a yellow head; lays eggs in the soil at the base of plants. Yellowish white, legless maggots tunnel into roots. |
| Celery | Aphid Leaf miner | See Beet. Adults are small, shiny, black flies with a bright yellow spot on upper thorax. Eggs are laid within the leaf. Larvae mine between upper and lower leaf surfaces. |

TABLE 6.16. INSECTS THAT ATTACK VEGETABLES (Continued)

| Стор | Insect | Description |
|-------------------------|---|--|
| Cucumber (See | Spider mite Tarnished plant bug Loopers and worms | See Bean. See Bean. See Broccoli, etc. |
| Vine Crops) Eggplant | Aphid Colorado potato beetle | See Artichoke. Oval beetle (3/8 in.) with 10 yellow and 10 black stripes, lays yellow eggs on undersides of leaves. Brick red, humpbacked larvae (1/2 in.) have black spots. Beetles and larvae are destructive leaf feeders. |
| Endive, escarole, | Flea beetle Leaf miner Spider mite Aphid | See Beet. See Bean. See Artichoke. |
| 1000000 | Flea beetle Leafhopper Leaf miner | See Beet. See Beet. See Beet. |
| Mustard greens | Looper Aphid Worms | See Broccoli. See Artichoke. See Broccoli, etc. |
| Okra | Aphid Green stinkbug | See Broccon, etc. See Artichoke. Large, flattened, shield-shaped, bright green bugs; various- sized nymphs with reddish markings. |
| Onion | Maggot | Slender, gray flies (¼ in.) lay eggs in soil. Small (⅓ in.) maggots bore into stems and bulbs. |
| | Thrips | Yellow or brown, winged or wingless, tiny (½5 in.). Damages plant by sucking plant sap, causing white areas or brown leaf tips. |

TABLE 6.16. INSECTS THAT ATTACK VEGETABLES (Continued)

| Crop | Insect | Description |
|----------------|--|--|
| Parsnip Pea | Carrot rust fly Aphid Seed maggot | See Carrot. See Artichoke. Housefly-like gray adults lay eggs that develop into maggots (¼ in.) with sharply |
| | Weevil | pointed heads. Brown-colored adults, marked by white, black, or gray (½5 in.), lay eggs on young pods. Larvae are small and whitish, with a brown head and mouth. Adults feed on blossoms. May infect seed before harvest and remain in |
| Pepper | Aphid Corn borer Flea beetle Leaf miner Maggot | hibernation during storage. See Artichoke. See Sweet corn. See Beet. See Beet. Housefly-sized adults have yellow stripes on body and brown stripes on wings. Larvae are typical maggots with pointed heads. |
| | Weevil | Black-colored, gray- or yellow-marked snout beetle, with the snout about half the length of the body. Grayish white larvae are legless and have a pale brown head. Both adults and larvae feed on buds and pods; adults also feed on foliage. |
| Potato | Aphid Colorado potato beetle | See Artichoke. See Eggplant. |

TABLE 6.16. INSECTS THAT ATTACK VEGETABLES (Continued)

| Crop | Insect | Description |
|-------------------------|-------------|---|
| | Cutworm | See Asparagus. |
| | Flea beetle | See Beet. |
| | Leafhopper | See Bean. |
| | Leaf miner | See Beet. |
| | Tuberworm | Small, narrow-winged, grayish brown moths (½ in.) lay eggs on foliage and exposed tubers in evening. Purplish or green caterpillars (¾ in.) with brown heads burrow into exposed tubers in the field or in storage. |
| | Wireworm | Adults are dark-colored, elongated beetles (click beetles). Yellowish, tough- bodied, segmented larvae feed on roots and tunnel through fleshy roots and tubers. |
| Radish | Maggot | See Broccoli, etc. |
| Rhubarb | Curculio | Yellow-dusted snout beetle that damages plants by puncturing stems. |
| Rutabaga, turnip | Flea beetle | See Beet. |
| Squash (See Vine Crops) | Maggot | See Broccoli, etc. |
| Southern pea | Curculio | Black, humpbacked snout beetle. Eats small holes in pods and peas. Larvae are white with yellowish head and no legs. |
| | Leafhopper | See Bean. |
| | Leaf miner | See Beet. |
| Spinach | Aphid | See Artichoke. |
| - | Leaf miner | See Beet. |
| | | |

TABLE 6.16. INSECTS THAT ATTACK VEGETABLES (Continued)

| Strawberry Aphid See Artichoke. Mites Several mite species attack strawberry. See Bean. | - |
|--|----------------------------|
| buawbeily, bee bean. | L |
| Tarnished plant bug See Bean. Thrips See Onion. | |
| Weevils Several weevil species attac strawberry. | .ck |
| Worms Several worm species attack strawberry. | :k |
| Sweet corn Armyworms Moths $(1\frac{1}{2} \text{ in.})$ with dark gr front wings and light-colo hind wings lay eggs on let undersides. Tan, green, or black worms $(1\frac{1}{4} \text{ in.})$ feed plant leaves and corn ears | ored eaf or ed on |
| Earworm See Bean. | |
| European corn borer Pale, yellowish moths (1 in.) with dark bands lay eggs undersides of leaves. Caterpillars hatch, feed of leaves briefly, and tunnel stalk and to the ear. | s on on |
| Flea beetle See Beet. | |
| Japanese beetle Shiny, metallic green with coppery brown wing cover oval beetles (½ in.). Sever leaf feeding results in a lacework appearance. Lar are grubs that feed on gra roots. | ere |
| Seed corn maggot See Bean. | |

TABLE 6.16. INSECTS THAT ATTACK VEGETABLES (Continued)

| Crop | Insect | Description |
|--------------|---------------------------------|--|
| | Stalk borer | Grayish moths (1 in.) lay eggs on weeds. Small, white, brown-striped caterpillars hatch and tunnel into weed and crop stalks. Most damage is usually at edges of fields. |
| Sweet potato | Flea beetle | See Beet. |
| Sweet poulto | Weevil | Blue-black and red adult (¼ in.) feeds on leaves and stems; grub-like larva tunnels into roots in the field and storage. |
| | Wireworm | See Potato. |
| Tomato | Aphid | See Artichoke. |
| | Colorado potato beetle | See Eggplant. |
| | Corn earworm (tomato fruitworm) | See Bean. |
| | Flea beetle | See Beet. |
| | Fruit fly | Small, dark-colored flies usually associated with overripe or decaying vegetables. |
| | Hornworm | Large (4–5 in.) moths lay eggs that develop into large (3–4 in.) green fleshy worms with prominent white lines on sides and a distinct horn at the rear. Voracious leaf feeders. |
| | Leaf miner | See Beet. |

TABLE 6.16. INSECTS THAT ATTACK VEGETABLES (Continued)

| Crop | Insect | Description |
|--|--|---|
| | Pinworm | Tiny yellow, gray, or green purple-spotted, brown-headed caterpillars cause small fruit lesions, mostly near calyx. Presence detected by large white blotches near folded leaves. |
| | Mite | See Bean. |
| | Stink bug | See Okra. |
| | White fly | Small, white flies that move when disturbed. |
| Vine Crops: cantaloupe, cucumber, pumpkin squash, watermelon | Aphid Cucumber beetle (spotted or striped) | See Artichoke. |
| | Leafhopper | See Bean. |
| | Leaf miner | See Beet. |
| | Mite | See Bean. |
| | Pickleworm | White moths (1 in.), later become greenish with black spots, with brown heads and brown-tipped wings with white centers and a conspicuous brush at the tip of the body, lay eggs on foliage. Brown-headed, white, later becoming greenish with black spots. Larvae (3/4 in.) feed on blossoms, leaves, and fruit. |
| | Squash bug | Brownish, flat stinkbug (5% in.). Nymphs (3% in.) are gray to green. Plant damage is due to sucking of plant sap. |

TABLE 6.16. INSECTS THAT ATTACK VEGETABLES (Continued)

| Crop | Insect | Description |
|------|-------------------|---|
| | Squash vine borer | Black, metallic moth (1½ in.) with transparent hind wings and abdomen ringed with red and black; lays eggs at the base of the plant. White caterpillars bore into the stem and tunnel throughout. |
| | White fly | See Tomato. |

IDENTIFICATION OF VEGETABLE INSECTS

Effective insect management requires accurate identification and a thorough knowledge of the insect's habits and life cycle. Previous editions of *Handbook for Vegetable Growers* contained drawings of selected insect pests of vegetables. Today, many fine websites that contain photographs of insect pests are available. Some Extension Services also have available CD-ROMs containing insect photographs. We have chosen to direct the reader to some of these websites to assist in the identification of insect pests. Although the photos are helpful in identifying pests, we encourage the grower to consult a knowledgeable insect expert to confirm the identification before any control strategy is implemented.

SOME USEFUL WEBSITES FOR INSECT IDENTIFICATION

California, http://www.ipm.ucdavis.edu/PMG/crops-agriculture.html; http://www.ipm.ucdavis.edu/PCA/pcapath.html#SPECIFIC

Colorado, http://lamar.colostate.edu/~gec/vg.htm

Florida, http://pests.ifas.ufl.edu (for a listing of web sites on insects, mites, and other topics and information regarding vegetable pest images and CDs)

Georgia, http://www.ent.uga.edu/veg/veg_crops.htm

Indiana, http://www.entm.purdue.edu/entomology/vegisite/

Iowa, http://www.ent.iastate.edu/imagegallery/

Kentucky, http://www.uky.edu/Agriculture/Entomology/entfacts/efveg.htm

Mississippi, http://msucares.com/insects/vegetable/

North Carolina, http://www.ces.ncsu.edu/depts/hort/consumer/ hortinternet/vegetable.html; http://www.ces.ncsu.edu/chatham/ag/ SustAg/insectlinks.html

South Carolina, http://entweb.clemson.edu/cuentres/cesheets/veg/

Texas, http://vegipm.tamu.edu/imageindex.html; http://insects.tamu.edu/images/insects/color/veindex.html

PEST MANAGEMENT IN ORGANIC PRODUCTION SYSTEMS

Diseases, insects, and nematodes can be controlled in organic vegetable production systems by combinations of tactics, including certain approved control materials. Pest management practices useful in organic vegetable production include:

Understanding the biology and ecology of pests

Encouraging natural enemies, predators, and parasites

Crop rotation

Trap crops

Crop diversification

Resistant varieties

Scouting for early detection

Optimal timing of planting (avoidance)

Controlling weed hosts

Controlling alternate host plants

Sanitation of field

Pest-free transplants

Tilling crop refuse

Exclusion, e.g., row covers

Traps, sticky tape, pheromone traps, etc.

Maintaining healthy crops

Maintaining optimum plant nutrition

Optimal pH control

Mulches

Spatial separation of crop and pest

Avoiding splashing water (drip irrigation instead of sprinklers)

Destroying cull piles

Providing for good air movement (proper plant and row spacing)

Using raised beds for water drainage

Flaming for weeds and Colorado potato beetle

Trellising or staking for air movement and to keep fruits from contact with the ground

Hand removal

Compost use (may contain antagonistic organism)

Using approved control materials

SELECTED RESOURCES FOR PEST CONTROL IN ORGANIC FARMING SYSTEMS

We located a variety of websites with information on organic pest management, many of which also contain links to other helpful sources of information. Some of these websites are listed below:

- B. Caldwell, E. Rosen, E. Sideman, A. Shelton, and C. Smart, Resource Guide for Organic Insect and Disease Management (Cornell University, 2005), http://www.nysaes.cornell.edu/pp/resourceguide/ index.php.
- C. Weeden, A. Shelton, Y. Li, and M. Hoffman, Biological Control: A Guide to Natural Enemies in North America (Cornell University, 2005), http://www.nysaes.cornell.edu/ent/biocontrol/.
- R. Hazzard and P. Westgate, Organic Insect Management in Sweet Corn (University of Massachusetts, 2004), http://www. umassvegetable.org/soil_crop_pest_mgt/pdf_files/organic_insect_management_in_sweet_corn.pdf.
- Organic Farming—National Sustainable Agriculture Information Service, http://attra.ncat.org/organic.html 2005). This site has many links to other organic farming publications by NCAT (National Center for Appropriate Technology).
- S. Koike, M. Gaskell, C. Fouche, R. Smith, and J. Mitchell, *Plant Disease Management for Organic Crops* (University of California—Davis, 2000), http://anrcatalog.ucdavis.edu/pdf7252.pdf.
- Insect and Disease Management in Organic Crop Systems (Manitoba Agriculture, Food, and Rural Initiatives, 2004), http://www.gov.mb.ca/ agriculture/crops/insects/fad64s00.html.
- Alternative Disease, Pest, and Weed Control (Alternative Farming Systems Information Center, 2003), http://www.nal.usda.gov/afsic/sbjdpwc.htm.
- Sustainable Agriculture Research and Education, http://www.sare.org/publications/organic/organic03.htm.
- Organic Gardening: A Guide to Resources, 1989–September 2003, http://www.nal.usda.gov/afsic/AFSIC_pubs/org_gar.htm#toc2c.
- Organic Trade Association, http://www.ota.com/index.html.
- Organic/Sustainable Farming: Idaho OnePlan (The Idaho Association of Soil Conservation Districts, 2004), http://www.oneplan.org/ index.shtml.

11 WILDLIFE CONTROL

DEER.

Repellants. May be effective for low-density deer populations. Apply before damage is expected, when no precipitation is expected, and when temperatures are $40-80^{\circ}$ F.

Fencing. Woven wire fences are the most effective and should be 8–10 ft tall. Electric fences may act as a deterrent. Some growers have success with 5- or 6-ft high-tensile electric fences, even though deer may be able to jump them.

RACCOONS

Many states have laws controlling the manner in which raccoons can be removed. Usually trapping is the only means of ridding a field of raccoons. Crops can be protected with a double-strand electric fence with wires at 5 and 10 in. above the ground.

BIRDS

Exclusion. Bird proof netting can be used to protect vegetables of high value.

Sound devices. Some success has been reported with recorded distress calls. Other sound devices such as propane guns may be effective for short periods. Use of these devices should be random and with a range of sound frequency and intervals.

Visual devices. Eye-spot balloons have been used with some success against grackles, blue jays, crows, and starlings and might be the control method of choice for urban farms. Reflective tape has been used with variable success and is labor intensive to install.

MICE

Habitat control. Remove any possible hiding or nesting sites near the field. Sometimes mice nest underneath polyethylene mulch not applied tightly to the ground, or in thick windbreaks.

- Traps and baits. Strategically placed traps and bait stations can be used to reduce mouse populations.
- Transplanting. The seed of some particularly attractive crops, such as curcurbits, is a favorite mouse food, and the seed is often removed from the ground soon after planting. One option to reduce stand losses is transplanting instead of direct seeding.

PART 5 WATER AND IRRIGATION

- 01 SUGGESTIONS FOR SUPPLYING WATER TO VEGETABLES
- 02 ROOTING OF VEGETABLES
- 03 SOIL MOISTURE
- 04 SURFACE IRRIGATION
- 05 OVERHEAD IRRIGATION
- 06 DRIP OR TRICKLE IRRIGATION
- 07 WATER QUALITY

01 SUGGESTIONS ON SUPPLYING WATER TO VEGETABLES

Plants in hot, dry areas lose more moisture into the air than those in cooler, more humid areas. Vegetables utilize and evaporate more water in the later stages of growth when size and leaf area are greater. The root system becomes deeper and more widespread as the plant ages.

Some vegetables, especially lettuce and sweet corn, have sparse root systems that do not come into contact with all the soil moisture in their root-depth zone. Cool-season vegetables normally root to a shallower depth than do warm-season vegetables and perennials.

When applying water, use enough to bring the soil moisture content of the effective rooting zone of the crop up to field capacity. This is the quantity of water that the soil holds against the pull of gravity.

The frequency of irrigation depends on the total supply of available moisture reached by the roots and the rate of water use. The first is affected by soil type, depth of wetted soil, and the depth and dispersion of roots. The latter is influenced by weather conditions and the age of the crops. Add water when the moisture in the root zone has been used to about the halfway point in the range of available moisture. Do not wait until vegetables show signs of wilting or develop color or texture changes that indicate they are not growing rapidly. A general rule is that vegetables need an average of 1 in. water per week from rain or supplemental irrigation in order to grow vigorously. In arid regions, about 2 in./week is required. These amounts of water may vary from 0.5 in./week early in the season to more than 1 in. later in the season.

IRRIGATION MANAGEMENT AND NUTRIENT LEACHING

Irrigation management is critical to success in nutrient management for mobile nutrients such as nitrogen. Irrigation management is particularly important in vegetable production in sandy soils where nitrogen is highly prone to leaching from the root zone with heavy rainfall or excessive irrigation. Leaching can occur with all irrigation systems if more water is applied than the soil can hold at one time. If the water-holding capacity of the soil is exceeded with any irrigation event, nutrient leaching can occur. Information is provided here to assist growers in understanding the rooting zone for crops and water-holding capacity of soils as well as application rates for various irrigation systems. Optimum irrigation management involves attention to these factors, knowing crop water needs, and keeping

an eye on soil moisture levels during the season. These factors vary for the crop being grown, the soil used, the season, and the climate, among other factors. Please consult your local Extension Service for specific information for your production area.

02 ROOTING OF VEGETABLES

ROOTING DEPTH OF VEGETABLES

The depth of rooting of vegetables is influenced by the soil profile. If it is a clay pan, hard pan, compacted layer, or other dense formation, the normal depth of rooting is not possible. Also, some transplanted vegetables may not develop root systems as deep as those of seeded crops. Although vegetables may root as deep as 18–24 in., most of the active root system for water uptake may be between 8 and 12 in.

TABLE 5.1. CHARACTERISTIC MAXIMUM ROOTING DEPTHS OF VARIOUS VEGETABLES

| Shallow | Moderately Deep | Deep |
|------------------|-----------------|--------------------|
| (18–24 in.) | (36–48 in.) | (More than 48 in.) |
| Broccoli | Bean, bush | Artichoke |
| Brussels sprouts | Bean, pole | Asparagus |
| Cabbage | Beet | Bean, lima |
| Cauliflower | Cantaloupe | Parsnip |
| Celery | Carrot | Pumpkin |
| Chinese cabbage | Chard | Squash, winter |
| Corn | Cucumber | Sweet potato |
| Endive | Eggplant | Tomato |
| Garlic | Mustard | Watermelon |
| Leek | Pea | |
| Lettuce | Pepper | |
| Onion | Rutabaga | |
| Parsley | Squash, summer | |
| Potato | Turnip | |
| Radish | _ | |
| Spinach | | |
| Strawberry | | |

03 SOIL MOISTURE

DETERMINING MOISTURE IN SOIL BY APPEARANCE OR FEEL

A shovel serves to obtain a soil sample from a shallow soil or when a shallow-rooted crop is being grown. A soil auger or soil tube is necessary to draw samples from greater depths in the root zone.

Squeeze the soil sample in the hand and compare its behavior with those of the soils listed in the Practical Soil-Moisture Interpretation Chart to get a rough idea of its moisture content.

TABLE 5.2. PRACTICAL SOIL-MOISTURE INTERPRETATION CHART

| | Clay (very sticky when moist; behaves like modeling clay) | Hard, baked, cracked surface. Hard clods difficult to break, sometimes have loose crumbs on surface. | Somewhat pliable; will ball under pressure. Forms a ball; ribbons out between thumb and forefinger. |
|-----------|--|--|--|
| Soil Type | Clay Loam (sticky and plastic when moist) | Dry clods that break down into powdery condition. | Somewhat crumbly, but will hold together with pressure. Forms a ball, somewhat plastic, sometimes sticks slightly with |
| Soil | Sandy Loam (gritty when moist; dirties fingers; contains some silt and clay) | Dry, loose, flows through fingers. | Still appears to be dry; will not form a ball. Tends to ball under pressure but seldom holds together. |
| | Sand (gritty when moist, almost like beach sand) | Dry, loose, single- grained; flows through fingers. | Still appears to be dry; will not form a ball with pressure. Same as sand under 50%. |
| | Amount of Readily Available Moisture Remaining for the Plant | Close to 0%. Little or no moisture available | 50% or less. Approaching time to irrigate 50–75%. Enough available moisture |

pressure.

| Easily ribbons out between fingers; feels slick. | Same as sand. | Puddles and free water form on surface. |
|--|---|---|
| Forms a ball and is very pliable; becomes slick readily if high in clay. | Same as sand. | Can squeeze out free water. |
| Forms weak ball, breaks easily, does not become slick. | Same as sand. | Free water is released Can squeeze out free with kneading. water. |
| Tends to stick together slightly, sometimes forms a very weak ball under pressure. | Upon squeezing, no free water appears; moisture is left on hand. | Free water appears when soil is |
| 75% to field capacity. Plenty of available moisture | At field capacity. Soil will not hold any more water (after draining) | Above field capacity. Unless water |

Adapted from R. W. Harris and R. H. Coppock (eds.), "Saving Water in Landscape Irrigation," University of California Division of Agricultural Science Leaflet 2976 (1978). Also from N. Klocke and P. Fischbach, Estimation, Soil Moisture by Appearance and Feet (University of Nebraska Cooperative Extension Service,

1998), http://ianrpubs.unl.edu/irrigation/g690.htm.

logged

bounced in hand.

drains out, soil will be water-

TABLE 5.3. FIELD DEVICES FOR MONITORING SOIL MOISTURE

| Method | Advantages | Disadvantages |
|--|---|---|
| Neutron moderation | inexpensive per location large sensing volume not affected by salinity stabile | safety hazard cumbersome expensive slow |
| Time Domain Reflectometry (TDR) | accurate easily expanded insensitive to normal salinity soil-specific calibration not needed | expensive problems under high salinity small sensing volume |
| Frequency Domain (FD) Capacitance and FDR | accurate after specific-soil calibration better than TDR in saline soils more flexible in probes than TDR less expensive than TDR | small sensing sphere needs careful installation needs specific soil calibration |
| Tensiometer | (some devices) direct reading minimal skill inexpensive not affected by salinity | limited suction range slow response time frequent maintenance requires intimate contact with soil |
| Resistance blocks | no maintenance simple, inexpensive | low resolution slow reaction time not suited for clays block properties change with time |
| Granular matrix sensors | no maintenance simple, inexpensive reduced problems compared to gypsum blocks | low resolution slow reaction time not suited for clays need to resaturate in dry soils |

Adapted from R. Munoz-Carpena, Field Devices for Monitoring Soil Water Content (University of Florida Extension Service Bulletin 343, 2004), http://edis.ifas.ufl.edu/ae266.

TABLE 5.4. APPROXIMATE SOIL WATER CHARACTERISTICS FOR TYPICAL SOIL CLASSES

| Characteristic | Sandy Soil | Loamy Soil | Clay Soil |
|--|------------|--------------------|--------------------|
| Dry weight 1 cu ft | 90 lb | 80 lb | 75 lb |
| Field capacity—% of dry weight | 10% | 20% | 35% |
| Permanent wilting percentage | 5% | 10% | 19% |
| Percent available water | 5% | 10% | 16% |
| Water available to plants | | | |
| lb/cu ft | 4 lb | 8 lb | 12 lb |
| in./ft depth | 3/4 in. | $1\frac{1}{2}$ in. | $2^{1/4}$ in. |
| gal/cu ft | ½ gal | 1 gal | $1\frac{1}{2}$ gal |
| Approximate depth of soil that will be wetted by each 1 in. water applied if half the available water has been used | 24 in. | 16 in. | 11 in. |
| Suggested lengths of irrigation runs | 330 ft | 660 ft | 1,320 ft |

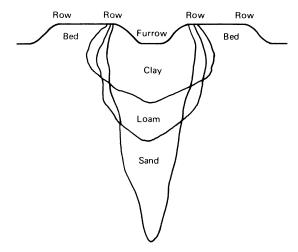


Figure 5.1. Arrangement of beds for furrow irrigation. Beds intended for two rows are usually on 36-, 40-, or 42-in. centers, with the surface 4-6 in. above the bottom of the furrow. The depth of penetration of an equal quantity of water varies with the class of soil as indicated.

04 SURFACE IRRIGATION

RATES OF WATER APPLICATION FOR VARIOUS IRRIGATION METHODS

The infiltration rate has an important bearing on the intensity and frequency with which water should be applied by any method of irrigation.

Normally, sandy soils have a high infiltration rate and clay soils have a low one. The rate is affected by soil texture, structure, dispersion, and the depth of the water table. The longer the water is allowed to run, the more the infiltration rate decreases.

With furrows, use a flow of water initially 2–3 times that indicated to fill the run as quickly as possible. Then cut back the flow to the indicated amount. This prevents excessive penetration at the head and equalizes the application of water throughout the whole furrow.

TABLE 5.5. APPROXIMATE FLOW OF WATER PER FURROW
AFTER WATER REACHES THE END OF THE FURROW

| | | Sle | ope of Land | (%) | | |
|---------------------------------------|-----------------------|---|--------------------------|--|--|--|
| | | 0-0.2 | 0.2-0.5 | 0.5-1 | | |
| Infiltration Rate of Soil (in./hr) | Length of Furrow (ft) | Flow o | f Water per (gal/min) | | | |
| High (1.5 or more) | 330 | 9 | 4 | 3 | | |
| | 660 $1,320$ | $\begin{array}{c} 20 \\ 45 \end{array}$ | 9 20 | $\begin{array}{c} 7 \\ 15 \end{array}$ | | |
| Medium (0.5–1.5) | 330 | 4 | 3 | 1.5 | | |
| , | 660 | 10 | 7 | 3.5 | | |
| | 1,320 | 25 | 15 | 7.5 | | |
| Low (0.1–0.5) | 330 | 2 | 1.5 | 1 | | |
| | 660 | 4 | 3.5 | 2 | | |
| | 1,320 | 9 | 7.5 | 4 | | |

TABLE 5.6. APPROXIMATE MAXIMUM WATER INFILTRATION RATES FOR VARIOUS SOIL TYPES

| Soil Type | Infiltration Rate ¹ (in./hr) | |
|--------------------|--|--|
| Sand | 2.0 | |
| Loamy sand | 1.8 | |
| Sandy loam | 1.5 | |
| Loam | 1.0 | |
| Silt and clay loam | 0.5 | |
| Clay | 0.2 | |

¹Assumes a full crop cover. For bare soil, reduce the rate by half.

TABLE 5.7. PERCENT OF AVAILABLE WATER DEPLETED FROM SOILS AT VARIOUS TENSIONS

| Tension— less than— (bars) ¹ | Loamy Sand | Sandy Loam | Loam | Clay |
|---|---------------|---------------|------|------|
| 0.3 | 55 | 35 | 15 | 7 |
| 0.5 | 70 | 55 | 30 | 13 |
| 0.8 | 77 | 63 | 45 | 20 |
| 1.0 | 82 | 68 | 55 | 27 |
| 2.0 | 90 | 78 | 72 | 45 |
| 5.0 | 95 | 88 | 80 | 75 |
| 15.0 | 100 | 100 | 100 | 100 |

Adapted from Cooperative Extension, University of California Soil and Water Newsletter No. 26 (1975).

¹1 bar = 100 kilopascals

TABLE 5.8. SPRINKLER IRRIGATION: APPROXIMATE APPLICATION OF WATER

| | Slope of | Land (%) |
|---------------------------------------|----------|------------------------|
| | 0–5 | 5–12 |
| Infiltration Rate of Soil (in./hr) | | oximate on (in./hr) |
| High (1.5 or more) | 1.0 | 0.75 |
| Medium (0.5–1.5) | 0.5 | 0.40 |
| Low (0.1–0.5) | 0.2 | 0.15 |

TABLE 5.9. BASIN IRRIGATION: APPROXIMATE AREA

| | Quantity of Water to be Supplied | | | | | | | |
|------------------------------------|----------------------------------|-------------------------------|--|--|--|--|--|--|
| | 450 gal/min or 1 cu ft/sec | 900 gal/min or 2 cu ft/sec | | | | | | |
| Infiltration Rate of Soil (in./hr) | * * | nate Area 'basin) | | | | | | |
| High (1.5 or more) | 0.1 | 0.2 | | | | | | |
| Medium (0.5–1.5) | 0.2 | 0.4 | | | | | | |
| Low (0.1–0.5) | 0.5 | 1.0 | | | | | | |

TABLE 5.10. VOLUME OF WATER APPLIED FOR VARIOUS FLOW RATES AND TIME PERIODS

| | Volume (acre-in.) Applied | | | | | | | | | |
|-----------------|---------------------------|-------|-------|--------|--|--|--|--|--|--|
| Flow Rate (gpm) | 1 hr | 8 hr | 12 hr | 24 hr | | | | | | |
| 25 | 0.06 | 0.44 | 0.66 | 1.33 | | | | | | |
| 50 | 0.11 | 0.88 | 1.33 | 2.65 | | | | | | |
| 100 | 0.22 | 1.77 | 2.65 | 5.30 | | | | | | |
| 200 | 0.44 | 3.54 | 5.30 | 10.60 | | | | | | |
| 300 | 0.66 | 5.30 | 7.96 | 15.90 | | | | | | |
| 400 | 0.88 | 7.07 | 10.60 | 21.20 | | | | | | |
| 500 | 1.10 | 8.84 | 13.30 | 26.50 | | | | | | |
| 1,000 | 2.21 | 17.70 | 26.50 | 53.00 | | | | | | |
| 1,500 | 3.32 | 26.50 | 39.80 | 79.60 | | | | | | |
| 2,000 | 4.42 | 35.40 | 53.00 | 106.00 | | | | | | |

 ${\it Adapted from A. Smajstrla\ and\ D.\ S.\ Harrison,\ Florida\ Cooperative\ Extension,\ Agricultural\ Engineering\ Fact\ Sheet\ AE18\ (1982).}$

TABLE 5.11. APPROXIMATE TIME REQUIRED TO APPLY VARIOUS DEPTHS OF WATER PER ACRE WITH DIFFERENT FLOWS¹

| Approximate Time Required per Acre for a Depth of: | 2 in. 3 in. 4 in. | hr min hr min hr min | 27 09 36 | 13 35 18 | 9 03 12 | 6 47 9 | 5 26 7 | 4 32 6 | 3 53 5 | 3 24 4 | 3 01 4 | 2 43 3 | | 2 28 3 | 2 28 3 2 16 3 | 2 28 3 2 16 3 2 05 2 | 11 39 2 28 3 18 1 31 2 16 3 01 1 24 2 05 2 48 1 18 1 56 2 35 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
|--|-------------------|-----------------------------------|----------|----------|---------|--------|-------------|-----------------|--------|--------|--------|----------------|------------|--------|------------------|----------------------------|--|--|
| | 1 in. | Approximate hr min acre-in./hr | | 1/4 4 | | 7/16 2 | $^{9/16}$ 1 | $^{11}/_{16}$ 1 | 3/4 1 | 7/8 1 | 1 | $1\frac{1}{8}$ | $1^{3/16}$ | | $1^{5/16}$ | $1^{5}/6$ $1^{7}/6$ | 15/16 17/16 19/16 | |
| riow of water | | sec-ft | 0.11 | 0.22 | 0.33 | 0.45 | 0.56 | 0.67 | 0.78 | 0.89 | 1.00 | 1.11 | 1.23 | | 1.34 | 1.34 1.45 | $\frac{1.34}{1.45}$ | 0.78 0.89 1.00 1.11 1.23 |
| | | gbm | 20 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 200 | 550 | 009 | | 650 | 650 700 | 350 400 450 500 550 600 |

TABLE 5.11. APPROXIMATE TIME REQUIRED TO APPLY VARIOUS DEPTHS OF WATER PER ACRE WITH DIFFERENT FLOWS¹ (Continued)

| | 4 in. | mim | 16 | 80 | 01 | 54 | 49 | 44 | 38 | 34 | 31 | 24 | 18 | 12 |
|--|-------|----------------------------|----------------|------|------|------------|-------|------------|-------|-----------|-----------|-------|-------|-------|
| epth of: | | hr | 21 | 23 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | 1 |
| cre for a L | 3 in. | mim | 42 | 36 | 31 | 56 | 21 | 18 | 14 | 11 | 80 | 03 | 58 | 54 |
| ired per A | | hr | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| Approximate Time Required per Acre for a Depth of. | 2 in. | mim | 80 | 04 | 00 | 22 | 54 | 52 | 49 | 47 | 45 | 42 | 39 | 36 |
| oroximate' | | hr | 1 | - | 1 | | | | | | | | | |
| Apı | 1 in. | mim | 34 | 32 | 30 | 29 | 27 | 26 | 25 | 24 | 23 | 21 | 20 | 18 |
| | | hr | | | | | | | | | | | | |
| Vater | | Approximate acre-in./hr | $1\frac{3}{4}$ | 17/8 | 2 | $2^{3/32}$ | 2% | $2^{5/16}$ | 27/16 | $2^{1/2}$ | $2^{5/8}$ | 2% | 3% | 35/16 |
| Flow of Water | | sec-ft | 1.78 | 1.89 | 2.01 | 2.12 | 2.23 | 2.34 | 2.45 | 2.56 | 2.67 | 2.90 | 3.12 | 3.34 |
| | | mdg | 800 | 850 | 006 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,300 | 1,400 | 1,500 |

¹If a sprinkler system is used, the time required should be increased by 2–10% to compensate for the water that will evaporate before reaching the soil.

TO DETERMINE THE WATER NEEDED TO WET VARIOUS DEPTHS OF SOIL

Example: You wish to wet a loam soil to a 12-in. depth when half the available water in that zone is gone. Move across the chart from the left on the 12-in. line. Stop when you reach the diagonal line marked "loams." Move upward from that point to the scale at the top of the chart. You will see that about 3/4 in. water is needed.

Depth of water required, inches, based on depletion of about half the available water in the effective root zone.

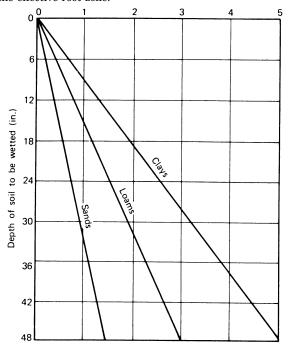


Figure 5.2. Chart for determining the amount of water needed to wet various depths of soil.

USE OF SIPHONS

Siphons of metal, plastic, or rubber can be used to carry water from a ditch to the area or furrow to be irrigated.

The inside diameter of the pipe and the head—the vertical distance from the surface of the water in the ditch to the surface of the water on the outlet side—determine the rate of flow.

When the outlet is not submerged, the head is measured to the center of the siphon outlet. You can determine how many gallons per minute are flowing through each siphon from the chart below.

Example: You have a head of 4 in. and are using 2-in. siphons. Follow the 4-in. line across the chart until you reach the curve for 2-in. siphons. Move straight down to the scale at the bottom. You will find that you are putting on about 28 gal/min.

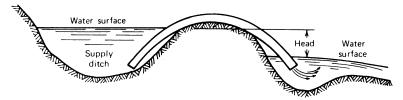


Figure 5.3. Method of measuring the head for water carried from a supply ditch to a furrow by means of a siphon. Adapted from University of California Division of Agricultural Science Leaflet 2956 (1977).

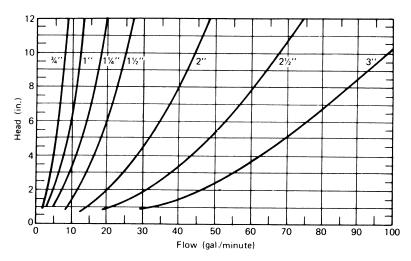


Figure 5.4. Chart for determining the flow of water through small siphons. Adapted from University of California Division of Agricultural Science Leaflet 2956 (1977). Also: E. C. Martin, *Measuring Water Flow in Surface Irrigation and Gated Pipe* (University of Arizona College Agriculture and Life Sciences, Arizona Water Series 31, 2004), http://cals.arizona.edu/pubs/water/az1329.pdf.

APPLICATION OF FERTILIZER IN WATER FOR FURROW IRRIGATION

There are certain limitations to the method of applying fertilizer solutions or soluble fertilizers in water supplied by furrow irrigation. You do not get uniform distribution of the fertilizer over the whole irrigated area. More of the dissolved material may enter the soil near the head than at the end of the furrow. You must know how long it will be necessary to run water in order to irrigate a certain area so as to meter the fertilizer solution properly. Soils vary considerably in their ability to absorb water.

Fertilizer solutions can be dripped from containers into the water. Devices are available that meter dry fertilizer materials into the irrigation water where they dissolve.

The rate of flow of dry soluble fertilizer or of fertilizer solutions into an irrigation head ditch can be calculated as follows:

$$\frac{\text{area to be}}{\text{nutrients in solution (lb/gal)}} = \frac{\text{amount of nutrient}}{\text{nutrients in solution (lb/gal)}} = \frac{\text{flow rate of}}{\text{fertilizer solution}}$$

$$\frac{\text{area to be}}{\text{irrigated (acres)} \times \text{fertilizer (lb/acre or gal/acre)}} = \frac{\text{flow rate of}}{\text{flow rate of irrigation (hr)}} = \frac{\text{flow rate of}}{\text{(lb/hr or gal/hr)}}$$

Knowing the gallons of solution per hour to be added to the irrigation water, you can adjust the flow from the tank as directed by the following table.

TABLE 5.12. RATE OF FLOW OF FERTILIZER SOLUTIONS

| Amount of Solution Desired (gal/hr) | Approximate Time (sec) to Fill a 4-oz Container | Approximate Time (sec) to Fill an 8-oz Container |
|---|---|---|
| 1/2 | 225 | 450 |
| 1 | 112 | 224 |
| 2 | 56 | 112 |
| 3 | 38 | 76 |
| 4 | 28 | 56 |
| 5 | 22 | 44 |
| 6 | 18 | 36 |
| 7 | 16 | 32 |
| 8 | 14 | 28 |
| 9 | 12 | 24 |
| 10 | 11 | 22 |
| 12 | 9 | 18 |
| 14 | 8 | 16 |
| 16 | 7 | 14 |
| 18 | 6 | 12 |
| 20 | 5.5 | 11 |

05 OVERHEAD IRRIGATION

LAYOUT OF A SPRINKLER SYSTEM

Each irrigation system presents a separate engineering problem. The advice of a competent engineer is essential. Many factors must be taken into consideration in developing a plan for the equipment:

Water supply available at period of greatest use
Distance from source of water to field to be irrigated
Height of field above water source and topography of the land
Type of soil (rate at which it absorbs water and its water-holding capacity)
Area to be irrigated
Desired frequency of irrigation
Quantity of water to be applied
Time on which application is to be made
Type of power available
Normal wind velocity and direction
Possible future expansion of the installation

Specific details of the plan must then include the following:

Size of power unit and pump to do the particular job Pipe sizes and lengths for mains and laterals Operating pressures of sprinklers Size and spacing of sprinklers Friction losses in the system

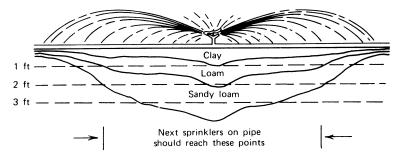


Figure 5.5. The diagram shows the approximate depth of penetration of available water from a 3-in. irrigation on various classes of soil. To avoid uneven water distribution, there should be enough distance between sprinklers to allow a 40% overlap in diameter of the area they are to cover.

TABLE 5.13. ACREAGE COVERED BY MOVES OF PIPE OF VARIOUS LENGTHS

| Lateral Move of Pipe (ft) | Length of Sprinkler Pipe (ft) | Area Covered per Move (acres |
|------------------------------|----------------------------------|---------------------------------|
| 20 | 2,640 | 1.21 |
| 20 | 1,320 | 0.61 |
| 20 | 660 | 0.30 |
| 20 | 330 | 0.15 |
| 30 | 2,640 | 1.82 |
| 30 | 1,320 | 0.91 |
| 30 | 660 | 0.46 |
| 30 | 330 | 0.23 |
| 40 | 2,640 | 2.42 |
| 40 | 1,320 | 1.21 |
| 40 | 660 | 0.61 |
| 40 | 330 | 0.30 |
| 50 | 2,640 | 3.03 |
| 50 | 1,320 | 1.52 |
| 50 | 660 | 0.76 |
| 50 | 330 | 0.38 |
| 60 | 2,640 | 3.64 |
| 60 | 1,320 | 1.82 |
| 60 | 660 | 0.91 |
| 60 | 330 | 0.46 |
| 80 | 2,640 | 4.85 |
| 80 | 1,320 | 2.42 |
| 80 | 660 | 1.21 |
| 80 | 330 | 0.61 |
| 100 | 2,640 | 6.06 |
| 100 | 1,320 | 3.03 |
| 100 | 660 | 1.52 |
| 100 | 330 | 0.76 |

CALCULATION OF RATES OF SPRINKLER APPLICATIONS

To determine the output per sprinkler needed to put on the desired rate of application:

$$\frac{\text{distance between}}{\text{sprinklers (ft)}} \times \frac{\text{distance between}}{\text{line settings (ft)}} \times \frac{\text{precipitation}}{\text{rate (in./hr)}}$$

$$96.3$$

= sprinkler rate (gal/minute)

Example:
$$\frac{30 \times 50 \times 0.4}{96.3} = 6.23$$
 gal/minute per sprinkler

To determine the rate at which water is being applied:

$$\frac{sprinkler\ rate}{(gal/minute)} \times 96.3 \\ \frac{distance\ between}{distance\ between} \times \frac{distance\ between}{sprinklers\ (ft)} = precipitation\ rate\ (in./hr)$$

Manufacturer's specifications give the gallons per minute for each type of sprinkler at various pressures.

Example:
$$\frac{10 \times 96.3}{40 \times 50} = 0.481 \text{ in./hr}$$

TABLE 5.14. PRECIPITATION RATES FOR VARIOUS NOZZLE SIZES, PRESSURE, AND SPACINGS

| | | | | Precipitatic | Precipitation Rate at Spacings $(in./hr)^1$ | ${ m lgs}~({ m in./hr})^1$ |
|----------------------|-------------------|---------------------------------|-----------------------------|-------------------------|---|----------------------------|
| Nozzle Size (in.) | Pressure (psi) | Discharge ¹ (gpm) | Diameter of Spray 2 (ft) | $30 	imes 40 	ext{ ft}$ | $30 	imes 45 \mathrm{ft}$ | 40 × 40 ft |
| 1/16 | 45 | 0.76 | 60–72 | 0.061 | | |
| 1/16 | 20 | 0.80 | 61-73 | 0.064 | | |
| 1/16 | 55 | 0.85 | 62-74 | 0.068 | | |
| 1/16 | 09 | 0.88 | 63-75 | 0.071 | | |
| 1/16 | 65 | 0.93 | 64–76 | 0.075 | | |
| 5/64 | 45 | 1.19 | 59–73 | 0.095 | 0.085 | |
| 5/64 | 20 | 1.25 | 62-72 | 0.100 | 0.089 | |
| 5/64 | 55 | 1.30 | 64-74 | 0.104 | 0.094 | 0.079 |
| 5/64 | 09 | 1.36 | 67-76 | 0.110 | 0.097 | 0.082 |
| 5/64 | 65 | 1.45 | 22–89 | 0.116 | 0.103 | 0.087 |
| 3/32 | 45 | 1.72 | 92-89 | 0.138 | 0.123 | 0.103 |
| 3/32 | 50 | 1.80 | 22-69 | 0.145 | 0.128 | 0.108 |
| 3/32 | 55 | 1.88 | 70–78 | 0.151 | 0.134 | 0.113 |
| 3/32 | 09 | 1.98 | 71–79 | 0.159 | 0.141 | 0.119 |
| 3/32 | 65 | 2.08 | 72–80 | 0.167 | 0.148 | 0.125 |
| 7/64 | 45 | 2.32 | 71–78 | 0.186 | 0.165 | 0.140 |
| 7/64 | 20 | 2.44 | 72–80 | 0.196 | 0.174 | 0.147 |
| 7/64 | 55 | 2.56 | 74-81 | 0.205 | 0.182 | 0.154 |

| $0.161 \\ 0.168$ | 0.183 | 0.193 | 0.204 | 0.213 | 0.222 |
|------------------|-------|-------|-------|-------|-------|
| 0.192 0.199 | 0.217 | 0.230 | 0.242 | 0.253 | |
| 0.216 0.224 | 0.244 | | | | |
| 76–82 77–83 | 76–82 | 78–82 | 79–83 | 80-84 | 81–85 |
| 2.69 2.79 | 3.04 | 3.22 | 3.39 | 3.55 | 3.70 |
| 60 65 | 45 | 50 | 55 | 09 | 65 |
| 7/64 7/64 | 1/8 | 1/8 | 1/8 | 1/8 | 1/8 |

(1977). Also, H. W. Otto and J. Meyer, "Tips on Irrigating Vegetables," Family Farm Series Publications: Vegetable Crop Production (University of California), Adapted from A. W. Marsh et al., "Solid Set Sprinklers for Starting Vegetable Crops," University of California Division of Agricultural Science Leaflet 2265 http://www.sfc.ucdavis.edu/pubs/family_farm_series/veg/irrigating/irrigating.html.

¹Three-digit numbers are shown here only to indicate the progression as nozzle size and pressure increase.

TABLE 5.15. GUIDE FOR SELECTING SIZE OF ALUMINUM PIPE FOR SPRINKLER LATERAL LINES

Maximum Number of Sprinklers to Use on Single Lateral Line

| Sprinkler Discharge | | Sprinkler S pe Diamet | | 40-ft Sprinkler Spacing for Pipe Diameter (in.): | | | | |
|------------------------|----|--------------------------|-----|--|----|-----|--|--|
| (gpm) | 2 | 3 | 4 | 2 | 3 | 4 | | |
| 0.75 | 47 | 95 | 200 | 43 | 85 | 180 | | |
| 1.00 | 40 | 80 | 150 | 36 | 72 | 125 | | |
| 1.25 | 34 | 69 | 118 | 31 | 62 | 104 | | |
| 1.50 | 30 | 62 | 100 | 28 | 56 | 92 | | |
| 1.75 | 27 | 56 | 92 | 25 | 50 | 83 | | |
| 2.00 | 25 | 51 | 84 | 23 | 46 | 76 | | |
| 2.25 | 23 | 47 | 78 | 21 | 43 | 71 | | |
| 2.50 | 21 | 44 | 73 | 19 | 40 | 66 | | |
| 2.75 | 20 | 42 | 68 | 18 | 38 | 62 | | |
| 3.00 | 19 | 40 | 65 | 17 | 36 | 58 | | |
| 3.25 | 18 | 38 | 62 | 16 | 34 | 56 | | |
| 3.50 | 17 | 36 | 59 | 15 | 32 | 53 | | |
| 3.75 | 16 | 34 | 56 | 14 | 31 | 51 | | |
| 4.00 | 16 | 33 | 54 | 14 | 30 | 48 | | |

TABLE 5.16. GUIDE TO MAIN-LINE PIPE SIZES¹

Water Flow (gpm) for Pipe Diameter (in.):

| Distance (ft) | 200 | 400 | 600 | 800 | 1,000 | 1,200 | 1,400 | 1,600 | 1,800 |
|---------------|-----|-----|-----|-----|-------|-------|-------|-------|-------|
| 200 | 3 | 4 | 5 | 5 | 6 | 6 | 6 | 7 | 7 |
| 400 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 |
| 600 | 4 | 5 | 6 | 7 | 7 | 7 | 8 | 8 | 8 |
| 800 | 4 | 5 | 6 | 7 | 7 | 8 | 8 | 8 | 10 |
| 1,000 | 5 | 6 | 6 | 7 | 8 | 8 | 8 | 10 | 10 |
| 1,200 | 5 | 6 | 7 | 7 | 8 | 8 | 10 | 10 | 10 |
| | | | | | | | | | |

 $^{^{1}}$ Using aluminum pipe (C = 120) with pressure losses ranging from 5 to 15 psi, average about 10.

TABLE 5.17. CONTINUOUS POWER OUTPUT REQUIRED AT TRACTOR POWER TAKEOFF TO PUMP WATER

| | | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 1,000 |
|-----------------------------|------------|-----|-------------|------|---------|--------|---------|-----------------|-----|-------|
| Pressure ¹ (psi) | Head¹ (ft) | | | Н | lorsepe | ower R | lequire | ed^2 | | |
| | 110 | 0.0 | 7 .0 | 11.7 | 10 | 20 | 00 | 0.7 | 0.1 | 00 |
| 50 | 116 | 3.9 | 7.8 | 11.7 | 16 | 20 | 23 | 27 | 31 | 39 |
| 55 | 128 | 4.3 | 8.7 | 13 | 17 | 22 | 26 | 30 | 35 | 43 |
| 60 | 140 | 4.7 | 9.5 | 14 | 19 | 24 | 28 | 33 | 38 | 47 |
| 65 | 151 | 5.1 | 10 | 15 | 20 | 25 | 30 | 36 | 41 | 51 |
| 70 | 162 | 5.5 | 11 | 16 | 22 | 27 | 33 | 38 | 44 | 55 |
| 75 | 173 | 5.8 | 12 | 17 | 23 | 29 | 35 | 41 | 47 | 58 |
| 80 | 185 | 6.2 | 12 | 19 | 25 | 31 | 37 | 44 | 50 | 62 |

Flow (gpm)

¹Including nozzle pressure, friction loss, and elevation lift.

² Pump assumed to operate at 75% efficiency.

TABLE 5.18. FLOW OF WATER REQUIRED TO OPERATE SOLID SET SPRINKLER SYSTEMS

Area Irrigated per Set (acres) 8 12 16 20 4 Irrigation rate gpm^1 cfs^2 (in./hr) gpm cfs gpm cfs cfs cfs gpm gpm 0.06 108 217 326 1.0 1.5 0.50.51.0 435 543 0.08 145 0.5 290 1.0 435 1.0 580 1.5 725 2.0 2.5 0.10 181 0.5 362 1.0 543 1.5 7242.0 905 0.12217 0.5 435 1.0 652 1.5 870 2.0 1,086 2.5 0.15 271 543 1.0 1.5 815 2.0 1,086 2.51,360 3.5 0.20 362 1.0 724 2.0 2.5 2.5 1.086 1.448 1.810 4.5

¹Gallons per minute pumped into the sprinkler system to provide an average precipitation rate as shown. Pump must have this much or slightly greater capacity.

 $^{^2}$ Cubic feet per second—the flow of water to the next larger $^{1}\!\!/_{\!\!2}$ cfs that must be ordered from the water district, assuming that the district accepts orders only in increments of $^{1}\!\!/_{\!\!2}$ cfs. Actually, $^{1}\!\!/_{\!\!2}$ cfs = 225 gpm.

APPLYING FERTILIZER THROUGH A SPRINKLER SYSTEM

Anhydrous ammonia, aqua ammonia, and nitrogen solutions containing free ammonia should not be applied by sprinkler irrigation because of the excessive loss of the volatile ammonia. Ammonium nitrate, ammonium sulfate, calcium nitrate, sodium nitrate, and urea are all suitable materials for use through a sprinkler system. The water containing the ammonia salts should not have a reaction on the alkaline side of neutrality, or the loss of ammonia will be considerable.

It is best to put phosphorus fertilizers directly in the soil by a band application. Potash fertilizers can be used in sprinkler lines. However, a soil application ahead of or at planting time usually proves adequate and can be made efficiently at that time.

Manganese, boron, and copper can be applied through the sprinkler system. See pages 242–243 for possible rates of application.

The fertilizing material is dissolved in a tank of water. Calcium nitrate, ammonium sulfate, and ammonium nitrate dissolve completely. The solution can then be introduced into the water line, either by suction or by pressure from a pump. See page 172 for relative solubility of fertilizer materials.

Introduce the fertilizer into the line slowly, taking 10–20 min to complete the operation.

After enough of the fertilizer solution has passed into the pipelines, shut the valve if suction by pump is used. This prevents unpriming the pump. Then run the system for 10–15 min to wash the fertilizer off the leaves. This also flushes out the lines, valves, and pump, if one has been used to force or suck the solution into the main line.

TABLE 5.19. AMOUNT OF FERTILIZER TO USE FOR EACH SETTING OF THE SPRINKLER LINE

| | | Nutrient per Setting of Sprinkler Line (lb): | | | | | | | | | |
|-----------------|-----------------|--|----|------|--------|---------|--------|--------|--------|-----|-----|
| Length | Lateral Move | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| of Line (ft) | of Line (ft) | | | Nutr | ient A | Applica | tion D | esired | (lb/ac | re) | |
| 330 | 40 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 |
| | 60 | 4 | 9 | 12 | 18 | 22 | 27 | 31 | 36 | 40 | 45 |
| | 80 | 6 | 12 | 18 | 24 | 30 | 36 | 42 | 48 | 54 | 60 |
| 660 | 40 | 6 | 12 | 18 | 24 | 30 | 36 | 42 | 48 | 54 | 60 |
| | 60 | 9 | 18 | 24 | 36 | 45 | 54 | 63 | 72 | 81 | 90 |
| | 80 | 12 | 24 | 36 | 48 | 60 | 72 | 84 | 96 | 108 | 120 |
| 990 | 40 | 9 | 18 | 24 | 36 | 45 | 54 | 63 | 72 | 81 | 90 |
| | 60 | 13 | 27 | 40 | 54 | 67 | 81 | 94 | 108 | 121 | 135 |
| | 80 | 18 | 36 | 54 | 72 | 90 | 108 | 126 | 144 | 162 | 180 |
| 1,320 | 40 | 12 | 24 | 36 | 48 | 60 | 72 | 84 | 96 | 108 | 120 |
| | 60 | 18 | 36 | 54 | 72 | 90 | 108 | 126 | 144 | 162 | 180 |
| | 80 | 24 | 48 | 72 | 96 | 120 | 144 | 168 | 192 | 216 | 240 |

It is necessary to calculate the actual pounds of a fertilizing material that must be dissolved in the mixing tank in order to supply a certain number of pounds of the nutrient to the acre at each setting of the sprinkler line. This is done as follows. To apply 40 lb nitrogen to the acre when the sprinkler line is 660 ft long and will be moved 80 ft, if sodium nitrate is used, divide 48 (as shown in the table) by 0.16 (the percentage of nitrogen in sodium nitrate). This equals 300 lb, which must be dissolved in the tank and applied at each setting of the pipe. Do the same with ammonium nitrate: Divide 48 by 0.33, which equals about 145 lbs.

SPRINKLER IRRIGATION FOR COLD PROTECTION

Sprinklers are often used to protect vegetables from freezing. Sprinkling provides cold protection because the latent heat of fusion is released when water changes from liquid to ice. When water is freezing, its temperature is near 32°F. The heat liberated as the water freezes maintains the temperature of the vegetable near 32°F even though the surroundings may be colder. As long as there is a mixture of both water and ice present, the temperature remains near 32°F. For all of the plant to be protected, it must be covered or encased in the freezing ice-water mixture. Enough water must be applied so that the latent heat released compensates for the heat losses.

References

- R. Evans and R. Sneed, Selection and Management of Efficient Handmove, Solid-set, and Permanent Sprinkler Irrigation Systems (North Carolina State University. Publication EBAE 91-152, 1996), http:// www.bae.ncsu.edu/programs/extension/evans/ebae-91-152.html.
- R. Snyder, *Principles of Frost Protection* (University of California FP005, 2001), http://biomet.ucdavis.edu/frostprotection/Principles%20of%20Frost%20Protection/FP005.html.

TABLE 5.20. APPLICATION RATE RECOMMENDED FOR COLD PROTECTION UNDER DIFFERENT WIND AND TEMPERATURE CONDITIONS

| | | Wind Speed (mph) |) |
|--------------------------------------|------|------------------|------|
| | 0-1 | 2-4 | 5–8 |
| Minimum Temperature Expected (°F) | | (in./hr) | |
| 27 | 0.10 | 0.10 | 0.10 |
| 26 | 0.10 | 0.10 | 0.14 |
| 24 | 0.10 | 0.16 | 0.30 |
| 22 | 0.12 | 0.24 | 0.50 |
| 20 | 0.16 | 0.30 | 0.60 |

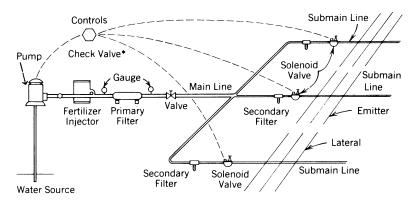
Adapted from D. S. Harrison, J. F. Gerber, and R. E. Choate, Sprinkler Irrigation for Cold Protection, Florida Cooperative Extension Circular 348 (1974).

06 DRIP OR TRICKLE IRRIGATION

Drip or *trickle irrigation* refers to the frequent slow application of water directly to the base of plants. Vegetables are usually irrigated by doublewall, thin-wall, or heavy-wall tubing to supply a uniform rate along the entire row.

Pressure in the drip lines typically varies from 8 to 10 psi and about 12 psi in the submains. Length of the drip lines may be as long as 600 ft, but 200–250 ft is more common. Rate of water application is about $\frac{1}{4}$ – $\frac{1}{2}$ gpm/100 ft of row. One acre of plants in rows 100 ft long and 4 ft apart use about 30 gpm water. Unless clear, sediment-free water is available, it is necessary to install a filter in the main line in order to prevent clogging of the small pores in the drip lines.

Drip irrigation provides for considerable saving in water application, particularly during early plant growth. The aisles between rows remain dry because water is applied only next to plants in the row.



^{*}A backflow preventer or vacuum breaker is required in some areas.

Figure 5.6. Drip or trickle irrigation system components.

TABLE 5.21. VOLUME OF WATER TO APPLY (GAL) BY DRIP IRRIGATION PER 100 LINEAR FT BED FOR A GIVEN WETTED SOIL VOLUME, AVAILABLE WATER-HOLDING CAPACITY, AND AN ALLOWABLE DEPLETION OF 1/2¹

| Wetted Soil Volume per | Available Water-holding Capacity (in. water per ft soil) | | | | | | | | | | |
|---------------------------|---|-------|--------|-----------|-----------|---------|-------|-------|--|--|--|
| 100 ft (cubic ft) | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 | 2.00 | | | |
| | | | (gal] | per 100 l | linear be | d feet) | | | | | |
| 25 | 2.2 | 4.3 | 6.5 | 8.7 | 10.8 | 13.0 | 15.2 | 17.3 | | | |
| 50 | 4.3 | 8.7 | 13.0 | 17.3 | 21.6 | 26.0 | 30.3 | 34.6 | | | |
| 75 | 6.5 | 13.0 | 19.5 | 26.0 | 32.5 | 39.0 | 45.5 | 51.9 | | | |
| 100 | 8.7 | 17.3 | 26.0 | 34.6 | 43.3 | 51.9 | 60.6 | 69.3 | | | |
| 125 | 10.8 | 21.6 | 32.5 | 43.3 | 54.1 | 64.9 | 75.8 | 86.6 | | | |
| 150 | 13.0 | 26.0 | 39.0 | 51.9 | 64.9 | 77.9 | 90.9 | 103.9 | | | |
| 175 | 15.2 | 30.3 | 45.5 | 60.6 | 75.8 | 90.9 | 106.1 | 121.2 | | | |
| 200 | 17.3 | 34.6 | 51.9 | 69.3 | 86.6 | 103.9 | 121.2 | 138.5 | | | |
| 225 | 19.5 | 39.0 | 58.4 | 77.9 | 97.4 | 116.9 | 136.4 | 155.8 | | | |
| 250 | 21.6 | 43.3 | 64.9 | 86.6 | 108.2 | 129.9 | 151.5 | 173.1 | | | |
| 275 | 23.8 | 47.6 | 71.4 | 95.2 | 119.0 | 142.8 | 166.7 | 190.5 | | | |
| 300 | 26.0 | 51.9 | 77.9 | 103.9 | 129.9 | 155.8 | 181.8 | 207.8 | | | |
| 350 | 30.3 | 60.6 | 90.9 | 121.2 | 151.5 | 181.8 | 212.1 | 242.4 | | | |
| 400 | 34.6 | 69.3 | 103.9 | 138.5 | 173.1 | 207.8 | 242.4 | 277.0 | | | |
| 450 | 39.0 | 77.9 | 116.9 | 155.8 | 194.8 | 233.8 | 272.7 | 311.7 | | | |
| 500 | 43.3 | 86.6 | 129.9 | 173.1 | 216.4 | 259.7 | 303.0 | 346.3 | | | |
| 550 | 47.6 | 95.2 | 142.8 | 190.5 | 238.1 | 285.7 | 333.3 | 380.9 | | | |
| 600 | 51.9 | 103.9 | 155.8 | 207.8 | 259.7 | 311.7 | 363.6 | 415.6 | | | |
| 700 | 60.6 | 121.2 | 181.8 | 242.4 | 303.0 | 363.6 | 424.2 | 484.8 | | | |
| 800 | 69.3 | 138.5 | 207.8 | 277.0 | 346.3 | 415.6 | 484.8 | 554.1 | | | |
| 900 | 77.9 | 155.8 | 233.8 | 311.7 | 389.6 | 467.5 | 545.4 | 623.3 | | | |

Adapted from G. A. Clark, C. D. Stanley, and A. G. Smajstrla, *Micro-irrigation on Mulched Bed Systems: Components, System Capacities, and Management* (Florida Cooperative Extension Service Bulletin 245, 2002), http://edis.ifas.ufl.edu/ae042.

¹An irrigation application efficiency of 90% is assumed.

TABLE 5.22. DISCHARGE PER GROSS ACRE (GPM/ACRE) FOR DRIP IRRIGATION BASED ON IRRIGATED LINEAR BED FEET AND EMITTER DISCHARGE

| Linear Bed | |] | Emitter D | ischarge | (gpm/100 | ft) | |
|------------------|------|------|-----------|-----------|----------|-------|-------|
| Feet per Acre | 0.25 | 0.30 | 0.40 | 0.50 | 0.75 | 1.00 | 1.50 |
| | | | (ga | l per min | /acre) | | |
| 3,000 | 7.5 | 9.0 | 12.0 | 15.0 | 22.5 | 30.0 | 45.0 |
| 3,500 | 8.8 | 10.5 | 14.0 | 17.5 | 26.3 | 35.0 | 52.5 |
| 4,000 | 10.0 | 12.0 | 16.0 | 20.0 | 30.0 | 40.0 | 60.0 |
| 4,500 | 11.3 | 13.5 | 18.0 | 22.5 | 33.8 | 45.0 | 67.5 |
| 5,000 | 12.5 | 15.0 | 20.0 | 25.0 | 37.5 | 50.0 | 75.0 |
| 5,500 | 13.8 | 16.5 | 22.0 | 27.5 | 41.3 | 55.0 | 82.5 |
| 6,000 | 15.0 | 18.0 | 24.0 | 30.0 | 45.0 | 60.0 | 90.0 |
| 6,500 | 16.3 | 19.5 | 26.0 | 32.5 | 48.8 | 65.0 | 97.5 |
| 7,000 | 17.5 | 21.0 | 28.0 | 35.0 | 52.5 | 70.0 | 105.0 |
| 7,500 | 18.8 | 22.5 | 30.0 | 37.5 | 56.3 | 75.0 | 112.5 |
| 8,000 | 20.0 | 24.0 | 32.0 | 40.0 | 60.0 | 80.0 | 120.0 |
| 8,500 | 21.3 | 25.5 | 34.0 | 42.5 | 63.8 | 85.0 | 127.5 |
| 9,000 | 22.5 | 27.0 | 36.0 | 45.0 | 67.5 | 90.0 | 135.0 |
| 9,500 | 23.8 | 28.5 | 38.0 | 47.5 | 71.3 | 95.0 | 142.5 |
| 10,000 | 25.0 | 30.0 | 40.0 | 50.0 | 75.0 | 100.0 | 150.0 |

Adapted from G. A. Clark, C. D. Stanley, and A. G. Smajstrla, *Micro-irrigation on Mulched Bed Systems: Components, System Capacities, and Management* (Florida Cooperative Extension Service Bulletin 245, 2002), http://edis.ifas.ufl.edu/ae042.

TABLE 5.23. VOLUME OF WATER (GAL WATER PER ACRE PER MINUTE) DELIVERED UNDER VARIOUS BED SPACINGS WITH ONE TAPE LATERAL PER BED AND FOR SEVERAL EMITTER FLOW RATES

| | Drip Tape | (| Emitter Flow Rate (gal per min per 100 ft) | | | | | | |
|-------------------|---------------|-------|--|----------|------|--|--|--|--|
| Bed Spacing (in.) | per Acre (ft) | 0.50 | 0.40 | 0.30 | 0.25 | | | | |
| | | | (gal per a | cre/min) | | | | | |
| 24 | 21,780 | 108.9 | 87.1 | 65.3 | 54.5 | | | | |
| 30 | 17,420 | 87.1 | 69.7 | 52.3 | 43.6 | | | | |
| 36 | 14,520 | 72.6 | 58.1 | 43.6 | 36.6 | | | | |
| 42 | 12,450 | 62.2 | 49.8 | 37.3 | 31.1 | | | | |
| 48 | 10,890 | 54.5 | 43.6 | 32.7 | 27.2 | | | | |
| 54 | 9,680 | 48.4 | 38.7 | 29.0 | 24.2 | | | | |
| 60 | 8,710 | 43.6 | 34.9 | 26.1 | 21.8 | | | | |
| 72 | 7,260 | 36.3 | 29.0 | 21.8 | 18.2 | | | | |
| 84 | 6,220 | 31.1 | 24.9 | 18.7 | 15.6 | | | | |
| 96 | 5,450 | 27.2 | 21.8 | 16.3 | 13.6 | | | | |
| 108 | 4,840 | 24.2 | 19.4 | 14.5 | 12.1 | | | | |
| 120 | 4,360 | 21.8 | 17.4 | 13.1 | 10.0 | | | | |

TABLE 5.24. VOLUME OF AVAILABLE WATER IN THE WETTED CYLINDRICAL DISTRIBUTION PATTERN UNDER A DRIP IRRIGATION LINE BASED ON THE AVAILABLE WATER-HOLDING CAPACITY OF THE SOIL

| | | W | etted Radius | $(in.)^1$ | |
|------------------------|----|-------------|---------------|---------------|-----|
| Available Water (%) | 6 | 9 | 12 | 15 | 18 |
| | | (gal availa | ble water per | 100 emitters) | |
| 3 | 9 | 20 | 35 | 55 | 79 |
| 4 | 12 | 26 | 47 | 74 | 106 |
| 5 | 15 | 33 | 59 | 92 | 132 |
| 6 | 18 | 40 | 71 | 110 | 159 |
| 7 | 21 | 46 | 82 | 129 | 185 |
| 8 | 24 | 53 | 94 | 147 | 212 |
| 9 | 26 | 60 | 106 | 165 | 238 |
| 10 | 29 | 66 | 118 | 184 | 265 |
| 11 | 32 | 73 | 129 | 202 | 291 |
| 12 | 35 | 79 | 141 | 221 | 318 |
| 13 | 38 | 86 | 153 | 239 | 344 |
| 14 | 41 | 93 | 165 | 257 | 371 |
| 15 | 44 | 99 | 176 | 276 | 397 |

Adapted from G. A. Clark and A. G. Smajstrla, *Application Volumes and Wetted Patterns for Scheduling Drip Irrigation in Florida Vegetable Production*, Florida Cooperative Extension Service Circular 1041 (1993).

¹ For a 1-ft depth of wetting.

TABLE 5.25. MAXIMUM APPLICATION TIMES FOR DRIP-IRRIGATED VEGETABLE PRODUCTION ON SANDY SOILS WITH VARIOUS WATER-HOLDING CAPACITIES

| Available Water- holding Capacity | | Tubing Flov | v Rate (gpm | per 100 ft) | |
|--------------------------------------|-----|-------------|-------------|-------------------------|-----|
| (in. water per in. soil) | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 |
| | | (maximum | min per ap | plication) ¹ | |
| 0.02 | 41 | 27 | 20 | 16 | 14 |
| 0.03 | 61 | 41 | 31 | 24 | 20 |
| 0.04 | 82 | 54 | 41 | 33 | 27 |
| 0.05 | 102 | 68 | 51 | 41 | 34 |
| 0.06 | 122 | 82 | 61 | 49 | 41 |
| 0.07 | 143 | 95 | 71 | 57 | 48 |
| 0.08 | 163 | 109 | 82 | 65 | 54 |
| 0.09 | 184 | 122 | 92 | 73 | 61 |
| 0.10 | 204 | 136 | 102 | 82 | 68 |
| 0.11 | 224 | 150 | 112 | 90 | 75 |
| 0.12 | 245 | 163 | 122 | 98 | 82 |

Adapted from C. D. Stanley and G. A. Clark, "Maximum Application Times for Drip-irrigated Vegetable Production as Influenced by Soil Type or Tubing Emission Characteristics," Florida Cooperative Extension Service Drip Tip No. 9305 (1993).

¹Assumes 10-in.-deep root zone and irrigation at 50% soil moisture depletion.

TREATING IRRIGATION SYSTEMS WITH CHLORINE

Chlorine can be used in irrigation systems to control the growth of algae and other microorganisms such as bacteria and fungi. These organisms are found in surface and ground water and can proliferate with the nutrients present in the water inside the drip tube. Filtration alone cannot remove all of these contaminants. Hypochlorous acid, the agent responsible for controlling microorganisms in drip tubes, is more active under slightly acidic water conditions. Chlorine gas, solid (calcium hypochlorite), or liquid (sodium hypochlorite) are sources of chlorine; however, all forms might not be legal for injecting into irrigation systems. For example, only sodium hypochlorite is legal for use in Florida.

When sodium hypochlorite is injected, the pH of the water rises. The resulting chloride and sodium ions are not detrimental to crops at typical injection rates. Chlorine materials should be injected at a rate to provide 1–2 ppm free residual chlorine at the most distant part of the irrigation system.

In addition to controlling microorganisms, hypochlorous acid also reacts with iron in solution to oxidize the ferrous form to the ferric form, which precipitates as ferric hydroxide. If irrigation water contains iron, this reaction with injected chlorine should occur before the filter system so the precipitate can be removed.

Adapted from G. A. Clark and A. G. Smajstrla, *Treating Irrigation Systems with Chlorine* (Florida Cooperative Extension Service Circular 1039, 2002), http://edis.ifas.ufl.edu/ae080.

TABLE 5.26. LIQUID CHLORINE (SODIUM HYPOCHLORITE)
INJECTION

| | % Concentration of chlorine in stock | | | | | | | |
|-----------------------|--------------------------------------|-------------------|-------------------|-----------|--|--|--|--|
| Treatment level (ppm) | 1 | 3 | 5.25 | 10 | | | | |
| | gal/hr injo | ection per 100 ga | ıl/min irrigation | flow rate | | | | |
| 1 | 0.54 | 0.18 | 0.10 | 0.05 | | | | |
| 2 | 1.1 | 0.36 | 0.21 | 0.14 | | | | |
| 3 | 1.6 | 0.54 | 0.31 | 0.16 | | | | |
| 4 | 2.2 | 0.72 | 0.41 | 0.22 | | | | |
| 5 | 2.7 | 0.90 | 0.51 | 0.27 | | | | |
| 6 | 3.3 | 1.1 | 0.62 | 0.32 | | | | |
| 8 | 4.4 | 1.5 | 0.82 | 0.43 | | | | |
| 10 | 5.5 | 1.8 | 1.0 | 0.54 | | | | |
| 15 | 8.3 | 2.8 | 1.5 | 0.81 | | | | |
| 20 | 11.0 | 3.7 | 2.1 | 1.1 | | | | |
| 30 | 16.5 | 5.5 | 3.1 | 1.6 | | | | |

Adapted from G. Clark and A. Smajstrla, *Treating Irrigation Systems with Chlorine* (Florida Cooperative Extension Service Circular 1039, 2002), http://edis.ifas.ufl.edu/ae080.

METHODS OF INJECTING FERTILIZER AND OTHER CHEMICAL SOLUTIONS INTO IRRIGATION PIPELINE

Four principal methods are used to inject fertilizers and other solutions into drip irrigation systems: (1) pressure differential; (2) the venturi (vacuum); (3) centrifugal pumps; and (4) positive displacement pumps. It is essential that irrigation systems equipped with a chemical injection system have a vacuum breaker (anti-siphon device) and a backflow preventer (check valve) installed upstream from the injection point. The vacuum-breaking valve and backflow preventer prevent chemical contamination of the water source in case of a water pressure loss or power failure. Operators may need a license to chemigate in some states. Local backflow regulations should be consulted prior to chemigation to insure compliance.

TABLE 5.27. REQUIRED VOLUME (GAL) OF CHEMICAL MIXTURE TO PROVIDE A DESIRED LEVEL OF AN ACTIVE CHEMICAL FOR DIFFERENT CONCENTRATIONS (LB/GAL) OF THE CHEMICAL IN THE STOCK SOLUTION

| | | ${ m S}_{ m mx}$ | | | | | | |
|------------------------------------|-------|------------------|---------|---------|---------|---------|----------|-----|
| | M | ass of Ch | nemical | (lb) Pe | er Gal | Stock S | Solution | n |
| Weight of Chemical Desired (lb) | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 2.0 | 3.0 | 4.0 |
| Desired (16) | 0.2 | 0.1 | 0.0 | 0.0 | 1.0 | 2.0 | 0.0 | 1.0 |
| | | | (gal | stock s | olution | n) | | |
| 20 | 100 | 50 | 33 | 25 | 20 | 10 | 7 | 5 |
| 40 | 200 | 100 | 67 | 50 | 40 | 20 | 13 | 10 |
| 60 | 300 | 150 | 100 | 75 | 60 | 30 | 20 | 15 |
| 80 | 400 | 200 | 133 | 100 | 80 | 40 | 27 | 20 |
| 100 | 500 | 250 | 167 | 125 | 100 | 50 | 33 | 25 |
| 150 | 750 | 375 | 250 | 188 | 150 | 75 | 50 | 38 |
| 200 | 1,000 | 500 | 333 | 250 | 200 | 100 | 67 | 50 |
| 250 | 1,250 | 625 | 417 | 313 | 250 | 125 | 83 | 63 |
| 300 | 1,500 | 750 | 500 | 375 | 300 | 150 | 100 | 75 |
| 350 | 1,750 | 875 | 583 | 438 | 350 | 175 | 117 | 88 |
| 400 | 2,000 | 1,000 | 667 | 500 | 400 | 200 | 133 | 100 |
| 450 | 2,250 | 1,125 | 750 | 563 | 450 | 225 | 150 | 113 |
| 500 | 2,500 | 1,250 | 833 | 625 | 500 | 250 | 167 | 125 |

Adapted from G. A. Clark, D. Z. Haman, and F. S. Zazueta, *Injection of Chemicals into Irrigation Systems: Rates, Volumes, and Injection Periods* (Florida Cooperative Extension Service Bulletin 250, 2002), http://edis.ifas.ufl.edu/ae116.

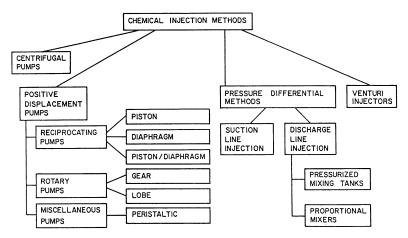


Figure 5.7. Classification of chemical injection methods for irrigation systems.

Adapted from D. Z. Haman, A. G. Smajstrla, and F. S. Zazueta, Chemical Injection Methods for Irrigation (Florida Cooperative Extension Service Circular 864, 2003). http://edis.ifas.ufl.edu/wi004.

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| | Injector | Advantages | Disadvantages |
|-----|--|--|---|
| 294 | Centrifugal Pumps Centrifugal pump injector | Low cost. Can be adjusted while running. | Calibration depends on system pressure. Cannot accurately control low injection rates. |
| | Positive Displacement Pumps | 8 | |
| | Piston pumps | High precision. Linear calibration. Very high pressure. Calibration independent of pressure. | High cost. May need to stop to adjust calibration. Chemical flow not continuous. |
| | Diaphragm pumps | Adjust calibration while injecting. High chemical resistance. | Nonlinear calibration. Calibration depends on system pressure. Medium to high cost. Chemical flow not continuous. |
| | Piston/diaphragm | High precision. Linear calibration. High chemical resistance. Very high pressure. Calibration independent of pressure. | High cost. May need to stop to adjust calibration. |

| Rotary Pumps | | |
|-------------------------------|---|---|
| Gear pumps Lobe pumps | Injection rate can be adjusted when running. | Fluid pumped cannot be abrasive. Injection rate is dependent on system pressure. Continuity of chemical flow depends on number of lobes in a lobe pump. |
| $\it Miscellaneous$ | | |
| Peristaltic pumps | High chemical resistance. Major adjustment can be made by changing tubing size. Injection rate can be adjusted when running. | Short tubing life expectancy. Injection rate dependent on system pressure. Low to medium injection pressure. |
| Pressure Differential Methods | , s | |
| Suction line injection | Very low cost. Injection can be adjusted while running. | Permitted only for surface water source and injection of fertilizer. Injection rate depends on main pump operation. |
| Discharge Line Injection | | |
| Pressurized mixing tanks | Low to medium cost. Easy operation. Total chemical volume controlled. | Variable chemical concentration. Cannot be calibrated accurately for constant initial materials. |
| Proportional mixers | Low to medium cost. Calibrate while operating. Injection rates accurately controlled. | Pressure differential required. Volume to be injected is limited by the size of the injector. Frequent refills required. |

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| Injector | Advantages | Disadvantages |
|---------------------------------|---|---|
| Venturi Injectors | | |
| Venturi injector | Low cost. Water powered. Simple to use. Calibrate while operating. No moving parts. | Pressure drop created in the system. Calibration depends on chemical level in the tank. |
| Combination Methods | | |
| Proportional mixers/ venturi | Greater precision than proportional mixer or venturi alone. | Higher cost than proportional mixer or venturi alone. |
| | | |

Adapted from D. Haman, A. Smajstrla, and F. Zazueta, Chemical Injection Methods for Irrigation (Florida Cooperative Extension Service Circular 864, 2003), http://edis.ifas.ufl.edu/wi004.

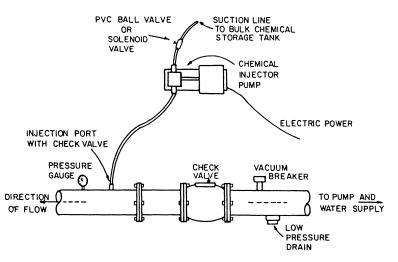


Figure 5.8. Single antisyphon device assembly.

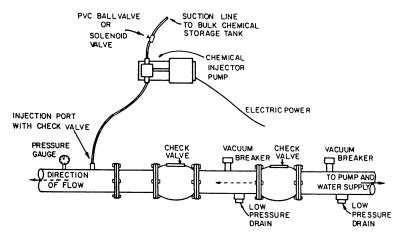


Figure 5.9. Double antisyphon device assembly.

Adapted from A. G. Smajstrla, D. S. Harrison, W. J. Becker, F. S. Zazueta, and D. Z. Haman, *Backflow Prevention Requirements for Florida Irrigation Systems*, Florida Cooperative Extension Service Bulletin 217 (1985).

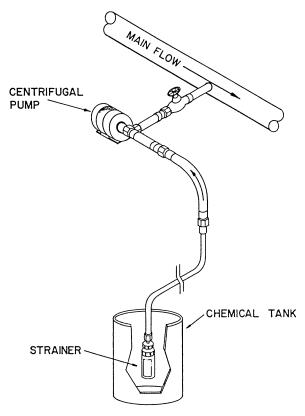


Figure 5.10. Centrifugal pump chemical injector.

Adapted from D. Z. Haman, A. G. Smajstrla, and F. S. Zazueta, Chemical Injection Methods for Irrigation (Florida Cooperative Extension Service Circular 864, 2003), http://edis.ifas.ufl.edu/wi004.

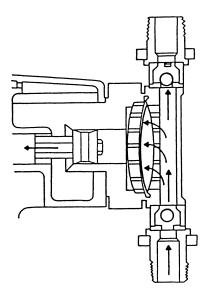


Figure 5.11. Diaphragm pump—suction stroke.

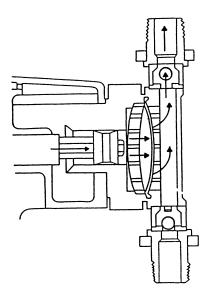


Figure 5.12. Diaphragm pump—discharge stroke.

Adapted from D. Z. Haman, A. G. Smajstrla, and F. S. Zazueta, Chemical Injection Methods for Irrigation (Florida Cooperative Extension Service Circular 864, 2003), http://edis.ifas.ufl.edu/wi004.

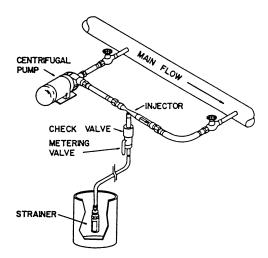


Figure 5.13. Venturi injector.

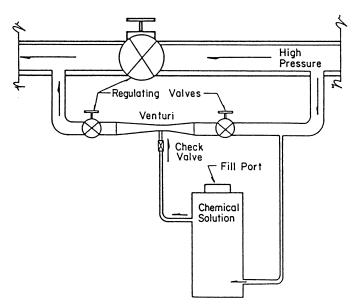


Figure 5.14. Proportional mixer/venturi.

 $\label{lem:condition} \begin{tabular}{ll} Adapted from D. Z. Haman, A. G. Smajstrla, and F. S. Zazueta, $\it Chemical Injection Methods for Irrigation (Florida Cooperative Extension Service Bulletin 864, 2003), $\it http://edis.ifas.ufl.edu/wi004. \\ \end{tabular}$

07 WATER QUALITY

TABLE 5.29. WATER QUALITY GUIDELINES FOR IRRIGATION¹

| | | Degree of Problem | |
|---|---------------------------------|-----------------------|---------------------------------|
| Situation | None | Increasing | Severe |
| Salinity | | | |
| EC (dS/m) or TDS (mg/L) | Less than 0.75 Less than 480 | 0.75–3.0 480–1,920 | More than 3.0 More than 1920 |
| Permeability | | | |
| Low EC (dS/m) or Low TDS (mg/L) | More than 0.5 More than 320 | 0.5–0 320–0 | 1 1 |
| SAR | Less than 6.0 | 6.0–9.0 | More than 9.0 |
| Toxicity of Specific Ions to Sensitive Crops Root Absorption | ve Crops | | |
| Sodium (evaluated by SAR) Chloride | SAR less than 3 | 3–9 | More than 9 |
| meq/L | Less than 2 | 2–10 | More than 10.0 |
| $^{-}$ $^{-}$ $^{-}$ | Less than 70 | 70–345 | More than 345 |
| Boron (mg/L) | 1.0 | 1.0-2.0 | 2.0 - 10.0 |

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| Degree of Problem | Increasing Severe | | More than 3 — 70 — | More than 3 — 100 — — | | 5–30 More than 30 | 1.5–8.5 More than 8.5 More than 520 |
|-------------------|-------------------|--|-------------------------------|--------------------------------|---------------|---|-------------------------------------|
| Degr | None | Sprinkler Irrigated) | Less than 3.0 Less than 70 | Less than 3.0 Less than 100 | | Less than 5 | Less than 1.0 Less than 40 |
| | Situation | RELATED TO FOLIAR ABSORPTION (SPRINKLER IRRIGATED) | Sodium meq/L mg/L | Chloride meq/L mg/L | MISCELLANEOUS | $\mathrm{NH_4}$ and $\mathrm{NO_3\text{-}N}$ (mg/L) | meq/L |

Adapted from D. S. Farnham, R. F. Hasek, and J. L. Paul, "Water Quality," University of California Division of Agricultural Science Leaflet 2995 (1985); and B. Hanson, S. Gratham, and A. Fulton, Agricultural Salinity and Drainage, University of California Division of Agriculture and Natural Resources Publication

¹Interpretation is related to type of problem and its severity but is modified by circumstances of soil, crop, and locality.

TABLE 5.30. MAXIMUM CONCENTRATIONS OF TRACE ELEMENTS IN IRRIGATION WATERS

| Element | For Waters Used Continuously on All Soils (mg/L) | For Use Up to 20 Years on Fine- textured Soils of pH 6.0–8.5 (mg/L) |
|------------|--|---|
| Aluminum | 5.0 | 20.0 |
| Arsenic | 0.10 | 2.0 |
| Beryllium | 0.10 | 0.50 |
| Boron | 0.75 | 2.0-10.0 |
| Cadmium | 0.01 | 0.05 |
| Chromium | 0.10 | 1.0 |
| Cobalt | 0.05 | 5.0 |
| Copper | 0.20 | 5.0 |
| Fluoride | 1.0 | 15.0 |
| Iron | 5.0 | 20.0 |
| Lead | 5.0 | 10.0 |
| Lithium | 2.5 | 2.5 |
| Manganese | 0.20 | 10.0 |
| Molybdenum | 0.01 | 0.05^{1} |
| Nickel | 0.20 | 2.0 |
| Selenium | 0.02 | 0.02 |
| Vanadium | 0.10 | 1.0 |
| Zinc | 2.00 | 10.0 |

Adapted from D. S. Farnham, R. F. Hasek, and J. L. Paul, "Water Quality," University of California Division of Agricultural Science Leaflet 2995 (1985).

 $^{^{1}}$ Only for acid, fine-textured soils or acid soils with relatively high iron oxide contents.

TABLE 5.31. ESTIMATED YIELD LOSS TO SALINITY OF IRRIGATION WATER

 $Electrical\ Conductivity\ of\ Water\\ (mmho/cm\ or\ dS/m)\ for\ Following\ \%\ Yield\ Loss$

| | · · · · · · · · · · · · · · · · · · · | | | |
|--------------|---------------------------------------|-----|-----|-----|
| Crop | 0 | 10 | 25 | 50 |
| Bean | 0.7 | 1.0 | 1.5 | 2.4 |
| Carrot | 0.7 | 1.1 | 1.9 | 3.1 |
| Strawberry | 0.7 | 0.9 | 1.2 | 1.7 |
| Onion | 0.8 | 1.2 | 1.8 | 2.9 |
| Radish | 0.8 | 1.3 | 2.1 | 3.4 |
| Lettuce | 0.9 | 1.4 | 2.1 | 3.4 |
| Pepper | 1.0 | 1.5 | 2.2 | 3.4 |
| Sweet potato | 1.0 | 1.6 | 2.5 | 4.0 |
| Sweet corn | 1.1 | 1.7 | 2.5 | 3.9 |
| Potato | 1.1 | 1.7 | 2.5 | 3.9 |
| Cabbage | 1.2 | 1.9 | 2.9 | 4.6 |
| Spinach | 1.3 | 2.2 | 3.5 | 5.7 |
| Cantaloupe | 1.5 | 2.4 | 3.8 | 6.1 |
| Cucumber | 1.7 | 2.2 | 2.9 | 4.2 |
| Tomato | 1.7 | 2.3 | 3.4 | 5.0 |
| Broccoli | 1.9 | 2.6 | 3.7 | 5.5 |
| Beet | 2.7 | 3.4 | 4.5 | 6.4 |
| | | | | |

Adapted from R. S. Ayers, Journal of the Irrigation and Drainage Division 103 (1977): 135-154.

TABLE 5.32. RELATIVE TOLERANCE OF VEGETABLE CROPS TO BORON IN IRRIGATION WATER $^{\scriptscriptstyle 1}$

| 10–15 ppm | 4–6 ppm | 2–4 ppm | 1–2 ppm | 0.5–1 ppm |
|-----------|---------------------------|---|---|--------------------------------------|
| Asparagus | Beet Parsley Tomato | Artichoke Cabbage Cantaloupe Cauliflower Celery Corn Lettuce Turnip | Broccoli Carrot Cucumber Pea Pepper Potato Radish | Bean Garlic Lima bean Onion |

 $Adapted\ from\ E.\ V.\ Mass, "Salt\ Tolerance\ of\ Plants," \ Applied\ Agricultural\ Research\ 1(1):12-26\ (1986).$

 $^{^{1}}$ Maximum concentrations of boron in soil water without yield reduction

PART 7

- 01 WEED MANAGEMENT STRATEGIES
- 02 WEED IDENTIFICATION
- 03 NOXIOUS WEEDS
- 04 WEED CONTROL IN ORGANIC FARMING
- 05 COVER CROPS AND ROTATION IN WEED MANAGEMENT
- 06 HERBICIDES
- 07 WEED CONTROL RECOMMENDATIONS

01 WEED MANAGEMENT STRATEGIES

Weeds reduce yield and quality of vegetables through direct competition for light, moisture, and nutrients as well as by interference with harvest operations. Early season competition is most critical, and a major emphasis on control should be made during this period. Common amaranth reduces yields of lettuce, watermelon, and muskmelon at least 20% if allowed to compete with these crops for only the first 3 weeks of growth. Weeds can be controlled, but this requires good management practices in all phases of production. Because there are many kinds of weeds, with much variation in growth habit, they obviously cannot be managed by a single method. The incorporation of several of the following management practices into vegetable strategies increases the effectiveness for controlling weeds.

Crop Competition

An often overlooked tool in reducing weed competition is to establish a good crop stand in which plants emerge and rapidly shade the ground. The plant that emerges first and grows the most rapidly is the plant with the competitive advantage. Utilization of good production management practices such as fertility, well-adapted varieties, proper water control (irrigation and drainage), and establishment of adequate plant populations is very helpful in reducing weed competition. Everything possible should be done to ensure that vegetables, not weeds, have the competitive advantage.

Crop Rotation

If the same crop is planted in the same field year after year, usually some weed or weeds are favored by the cultural practices and herbicides used on that crop. By rotating to other crops, the cultural practices and herbicide program are changed. This often reduces the population of specific weeds tolerant in the previous cropping rotation. Care should be taken, however, to not replant vegetables in soil treated with a nonregistered herbicide. Crop injury as well as vegetables containing illegal residues may result. Check the labels for plant-back limitations before application and planting rotational crops.

Mechanical Control

Mechanical control includes field preparation by plowing or disking, cultivation, mowing, hoeing, and hand pulling of weeds. Mechanical control

practices are among the oldest weed management techniques. Weed control is a primary reason for preparing land for crops planted in rows. Seedbed preparation by plowing or disking exposes many weed seeds to variations in light, temperature, and moisture. For some weeds, this process breaks weed seed dormancy, leading to early season control with herbicides or additional cultivation. Cultivate only deep enough in the row to achieve weed control; deep cultivation may prune roots, bring weed seeds to the surface, and disturb the soil previously treated with a herbicide. Follow the same precautions between rows. When weeds can be controlled without cultivation, there is no advantage to the practice. In fact, there may be disadvantages, such as drying out the soil surface, bringing weed seeds to the surface, and disturbing the root system of the crop.

Mulching

The use of polyethylene mulch increases yield and earliness of vegetables. The proper injection of fumigants under the mulch controls nematodes, soil insects, soil borne diseases, and weed seeds. Mulches act as a barrier to the growth of many weeds. Nutsedge, however, is one weed that can and will grow through the mulch.

Prevention

Preventing weeds from infesting or reinfesting a field should always be considered. Weed seed may enter a field in a number of ways. It may be distributed by wind, water, machinery, in cover crop seed, and other means. Fence rows and ditch banks are often neglected when controlling weeds in the crop. Seed produced in these areas may move into the field. Weeds in these areas can also harbor insects and diseases (especially viruses) that may move onto the crop. It is also important to clean equipment before entering fields or when moving from a field with a high weed infestation to a relatively clean field. Nutsedge tubers especially are moved easily on disks, cultivators, and other equipment.

Herbicides

Properly selected herbicides are effective tools for weed control. Herbicides may be classified several ways depending on how they are applied and their mode of action in or on the plant. Generally, herbicides are either soil applied or foliage applied. They may be selective or nonselective, and they may be either contact or translocated through the plant. For example, paraquat is a foliage-applied, contact, nonselective herbicide, whereas

atrazine usually is described as a soil-applied, translocated, selective herbicide.

Foliage-applied herbicides may be applied to leaves, stems, and shoots of plants. Herbicides that kill only those parts of the plants they touch are contact herbicides. Those herbicides that are taken into the plant and moved throughout it are translocated herbicides. Paraquat is a contact herbicide, whereas glyphosate (Roundup) or Sethoxydim (Poast) are translocated herbicides. For foliage-applied herbicides to be effective, they must enter the plant. Good coverage is very important. Most foliage-applied herbicides require either the addition of a specified surfactant or a specified formulation to be used for best control.

Soil-applied herbicides are either applied to the surface or incorporated. Surface-applied herbicides require rainfall or irrigation shortly after application for best results. Lack of moisture often results in poor weed control. Incorporated herbicides are not dependent on rainfall or irrigation and generally give more consistent and wider-spectrum control. They do, however, require more time and equipment for incorporation. Herbicides that specify incorporation into the soil improve the contact of the herbicide with the weed seed and/or minimize the loss of the herbicide by volatilization or photodecomposition. Some herbicides, if not incorporated, may be lost from the soil surface. Although most soil-applied herbicides must be moved into the soil to be effective, the depth of incorporation into the soil can be used to achieve selectivity. For example, if a crop seed is planted 2 in. deep in the soil and the herbicide is incorporated by irrigation only in the top 1 in., where most of the problem weed seeds are found, the crop roots will not come in contact with the herbicide. If too much irrigation or rain moves the herbicide down into the crop seed zone or if the herbicide is incorporated mechanically too deep, crop injury may result.

Adapted from W. M. Stall, "Weed Management," in S. M. Olson and E. H. Simone (eds.), Commercial Vegetable Production Handbook for Florida (Florida Cooperative Extension Service, Serv. SP-170, 2004), http://edis.ifas.ufl.edu/cv113.

02 WEED IDENTIFICATION

Accurate identification of the particular weed species is the first step to controlling the problem. Several university and cooperative extension websites offer information about and assistance with identifying weeds. Some sources offer information across crops and commodities, and many have very good photos of weed species. As good as these websites are for assisting in weed identification, the grower is encouraged to obtain confirmation of identification from a knowledgeable weed expert before implementing a weed control strategy. The following websites, among many others, offer photos and guides to the identification of weeds.

California, www.ipm.ucdavis.edu/PMG/weeds_common.html
Illinois, http://web.aces.uiuc.edu/weedid
Iowa, http://www.weeds.iastate.edu/weed-id/weedid.htm
Minnesota, http://www.extension.umn.edu/distribution/cropsystems/DC1352.html

Missouri, http://www.plantsci.missouri.edu/fishel/field_crops.htm New Jersey, http://www.rce.rutgers.edu/weeds Virginia, http://www.ppws.vt.edu/weedindex.htm

03 NOXIOUS WEEDS

Noxious weeds are plant species so injurious to agricultural crop interests that they are regulated or controlled by federal and/or state laws. Propagation, growing, or sales of these plants may be controlled. Some states divide noxious weeds into "prohibited" species, which may not be grown or sold, and "restricted" species, which may occur in the state and are considered nuisances or of economic concern for agriculture. States have different lists of plants considered noxious. The federal website below leads to state-based information about noxious weeds.

http://www.ars-grin.gov/cgi-bin/npgs/html/taxweed.pl (2005)

04 WEED CONTROL IN ORGANIC FARMING

Weeds can be a serious threat to vegetable production in organic systems. Weed control is one of the most costly activities in successful organic vegetable production. Some of the recommended main organic weed control strategies include:

Rotate crops.

Cover crops to compete with weeds in the non-crop season.

Be knowledgeable about potential weed contamination of manures, composts, and organic soil amendments.

Employ mechanical and manual control through cultivation, hoeing, mowing, hand weeding, etc.

Clean equipment to minimize transfer of weed propagules from one field to another

Control weeds at the crop perimeter.

Completely till crop and weeds after final harvest.

Plan for fallow periods with mechanical destruction of weeds.

Use the stale seedbed technique when appropriate.

Use approved weed control materials selected from the Standards lists below.

Encourage crop competition due to optimum crop vigor, correct plant spacing, or shading of weeds.

Use approved soil mulching practices to smother weed seedlings around crops or in crop alleys.

Practice precise placement of fertilizers and irrigation water to minimize availability to weeds in walkways and row middles.

Websites offering information on weed control practices in organic vegetable production include:

- Organic Materials Review Institute (OMRI), http://www.omri.org
- National Organic Standards Board (NOSB), http://www.ams.usda.gov/ nosb/index.htm
- National Organic Program (NOP), http://www.ams.usda.gov/nop/nop/nophome.html
- Weed Management Menu—Sustainable Farming Connection, http://www.ibiblio.org/farming-connection/weeds/home.htm

- National Sustainable Agriculture Information Service, http://www.attra.org
- G. Boyhan, D. Granberry, W. T. Kelley, and W. McLaurin, Growing Vegetables Organically (University of Georgia, 1999), http:// pubs.caes.uga.edu/caespubs/pubcd/b1011-w.html.

05 COVER CROPS AND ROTATION IN WEED MANAGEMENT

Vegetable growers can take advantage of certain cover crops to help control weeds in vegetable production systems and crop rotation systems. Cover crops compete with weeds, reducing the growth and weed seed production capacity of weeds. Cover crops help build soil organic matter and can lead to more vigorous vegetable crops that compete more effectively with weeds. Rotation introduces weed populations to different crops with different weed control options and helps keep herbicide-resistant weed populations from becoming established.

Some websites for cover crops and rotation in vegetable production:

Michigan, www.kbs.msu.edu/extension/covercrops/home.htm New York, http://www.nysaes.cornell.edu/recommends/4frameset.html

06 HERBICIDES

WEED CONTROL WITH HERBICIDES

Chemical weed control minimizes labor and is effective if used with care. The following precautions should be observed:

- 1. Do not use a herbicide unless the label states that it is registered for that particular crop. Be sure to use as directed by the manufacturer.
- 2. Use herbicides so that no excessive residues remain on the harvested product, which may otherwise be confiscated. Residue tolerances are established by the U.S. Environmental Protection Agency (EPA).
- 3. Note that some herbicides kill only certain weeds.
- 4. Make certain the soil is sufficiently moist for effective action of preemergence sprays. Do not expect good results in dry soil.
- 5. Keep in mind that postemergence herbicides are most effective when conditions favor rapid weed germination and growth.
- 6. Avoid using too much herbicide. Overdoses can injure the vegetable crop. Few crops, if any, are entirely resistant.
- Use less herbicide on light sandy soils than on heavy clay soils.
 Muck soils require somewhat greater rates than do heavy mineral soils.
- 8. When using wettable powders, be certain the liquid in the tank is agitated constantly as spraying proceeds.
- 9. Use a boom and nozzle arrangement that fans out the material close to the ground in order to avoid drift.
- 10. Thoroughly clean spray tank after use.

CLEANING SPRAYERS AFTER APPLYING HERBICIDES

Sprayers must be kept clean to avoid injury to the crop on which they are to be used for applying insecticides or fungicides as well as to prevent possible deterioration of the sprayers after use of certain materials.

1. Rinse all parts of sprayer with water before and after any special cleaning operation is undertaken.

- 2. If in doubt about the effectiveness of water alone to clean the herbicide from the tank, pump, boom, hoses, and nozzles, use a cleaner. In some cases, it is desirable to use activated carbon to reduce contamination.
- 3. Fill the tank with water. Use one of the following materials for each 100 gal water: 5 lb paint cleaner (trisodium phosphate), 1 gal household ammonia, or 5 lb sal soda.
- 4. If hot water is used, let the solution stand in the tank for 18 hr. If cold water is used, leave it for 36 hr. Pump the solution through the sprayer.
- 5. Rinse the tank and parts several times with clear water.
- 6. If copper has been used in the sprayer before a weed control operation is performed, put 1 gal vinegar in 100 gal water and let the solution stay in the sprayer for 2 hr. Drain the solution and rinse thoroughly. Copper interferes with the effectiveness of some herbicides.

DETERMINING RATES OF APPLICATION OF WEED CONTROL MATERIALS

Commercially available herbicide formulations differ in their content of the active ingredient. The label indicates the amount of the active ingredient (lb/gal). Refer to this amount in the table to determine how much of the formulation you need in order to supply the recommended amount of the active ingredient per acre. For calibration of herbicide application equipment, see pages 328–339.

TABLE 7.1. HERBICHDE DILUTION TABLE: QUANTITY OF LIQUID CONCENTRATES TO USE TO GIVE DESIRED DOSAGE OF ACTIVE CHEMICAL

| Active Ingredient Content of Liquid | | A | active Ing | gredien b/acre) | | l | |
|--|-------|--------|------------|--------------------|-----------|---------|------|
| Concentrate (lb/gal) | 0.125 | 0.25 | 0.50 | 1 | 2 | 3 | 4 |
| | | Liquid | Concenti | rate to | Use (pint | t/acre) | |
| 1 | 1.0 | 2.0 | 4.0 | 8.0 | 16.0 | 24.0 | 32.0 |
| $1\frac{1}{2}$ | 0.67 | 1.3 | 2.6 | 5.3 | 10.6 | 16.0 | 21.3 |
| 2 | 0.50 | 1.0 | 2.0 | 4.0 | 8.0 | 12.0 | 16.0 |
| 3 | 0.34 | 0.67 | 1.3 | 2.7 | 5.3 | 8.0 | 10.7 |
| 4 | 0.25 | 0.50 | 1.0 | 2.0 | 4.0 | 6.0 | 8.0 |
| 5 | 0.20 | 0.40 | 0.80 | 1.6 | 3.2 | 4.8 | 6.4 |
| 6 | 0.17 | 0.34 | 0.67 | 1.3 | 2.6 | 4.0 | 5.3 |
| 7 | 0.14 | 0.30 | 0.60 | 1.1 | 2.3 | 3.4 | 4.6 |
| 8 | 0.125 | 0.25 | 0.50 | 1.0 | 2.0 | 3.0 | 4.0 |
| 9 | 0.11 | 0.22 | 0.45 | 0.9 | 1.8 | 2.7 | 3.6 |
| 10 | 0.10 | 0.20 | 0.40 | 0.8 | 1.6 | 2.4 | 3.2 |

Adapted from Spraying Systems Co., Catalog 36, Wheaton, Ill. (1978).

Additional Conversion Tables

http://pmep.cce.cornell.edu/facts-slides-self/facts/gen-peapp-conv-table.html http://pubs.caes.uga.edu/caespubs/pubcd/b931.htm

SUGGESTED CHEMICAL WEED CONTROL PRACTICES

State recommendations for herbicides vary because the effect of herbicides is influenced by growing area, soil type, temperature, and soil moisture. Growers should consult local authorities for specific recommendations. The EPA has established residue tolerances for those herbicides that may leave injurious residues in or on a harvested vegetable and has approved certain materials, rates, and methods of application. Laws regarding vegetation and herbicides are constantly changing. Growers and commercial applicators should not use a chemical on a crop for which the compound is not registered. Herbicides should be used exactly as stated on the label regardless of information presented here. Growers are advised to give special attention to plant-back restrictions.

07 WEED CONTROL RECOMMENDATIONS

The Cooperative Extension Service in each state publishes recommendations for weed control practices. We present below some websites containing recommendations for weed control in vegetable crops. The list is not exhaustive, and these websites are presented for information purposes. Because weed control recommendations, especially recommended herbicides, may differ from state to state and year to year, growers are encouraged to consult the proper experts in their state for the latest information about weed control.

SELECTED WEBSITES FOR VEGETABLE WEED CONTROL RECOMMENDATIONS

- A. S. Culpepper, "Commercial Vegetables: Weed Control," in 2005 Georgia Pest Management Handbook, Commercial Edition, http://pubs.caes.uga/caespubs/PMH/PMH-com-veggie-weed.pdf.
- D. W. Monks and W. E. Mitchem, "Chemical Weed Control in Vegetable Crops," in 2005 North Carolina Agricultural Chemicals Manual, http://ipm.ncsu.edu/agchem/chptr8/817.pdf.
- R. D. William, "Weed Management in Vegetable Crops," in Pacific Northwest Weed Management Handbook. (2005), http://pnwpest.org/ pnw/weeds.
- B. H. Zandstra, 2005 Weed Control Guide for Vegetable Crops
 Michigan State University Extension Bulletin E-433 (Nov. 2004),
 http://web4.msue.msu.edu/veginfo/bulletins/E433_2005.pdf.
- Commercial Vegetables Disease, Nematode, and Weed Control Recommendations for 2005 (Alabama), http://www.aces.edu/pubs/docs/A/ANR-0500-A/veg.pdf.
- Weed Management, (New York) Integrated Crop and Pest Management Guidelines for Commercial Vegetable Production, (2005), http://www.nysaes.cornell.edu/recommends/4frameset.html.
- S. Post, F. Hale, D. Robinson, R. Straw, and J. Wills, The 2005
 Tennessee Commercial Vegetable Disease, Insect, and Weed Control
 Guide, http://www.utextension.utk.edu/publications/pbfiles/
 PB1282.pdf.
- Florida weed control information can be found at http://
 edis.ifas.ufl.edu/ and search for "weed control" and author = "W. M.
 Stall." This brings up weed control documents for individual
 vegetables.
- Ontario, Canada, http://www.omafra.gov.on.ca/english/environment/ hort/references.htm (2005).

PART 8

HARVESTING, HANDLING, AND STORAGE

- 01 FOOD SAFETY
- 02 GENERAL POSTHARVEST HANDLING PROCEDURES
- 03 PREDICTING HARVEST DATES AND YIELDS
- 04 COOLING VEGETABLES
- 05 VEGETABLE STORAGE
- 06 CHILLING AND ETHYLENE INJURY
- 07 POSTHARVEST DISEASES
- 08 VEGETABLE QUALITY
- 09 U.S. STANDARDS FOR VEGETABLES
- 10 MINIMALLY PROCESSED VEGETABLES
- 11 CONTAINERS FOR VEGETABLES
- 12 VEGETABLE MARKETING

01 FOOD SAFETY

Additional information on food safety can be found on these websites:

http://www.jifsan.umd.edu/gaps.html

http://www.cfsan.fda.gov.html

 $http://www.cals.ncsu.edu/hort_sci/hsfoodsafety.html\\$

http://www.ces.ncsu.edu/depts/foodsci/agentinfo/

http://foodsafe.msu.edu/

http://ucgaps.ucdavis.edu/

http://www.gaps.cornell.edu/

http://www.foodriskclearinghouse.umd.edu/

http://www.foodsafety.gov/

http://www.extension.iastate.edu/foodsafety/

http://www.cdc.gov/foodsafety/edu.htm

FOOD SAFETY ON THE FARM

Potential On-Farm Contamination Sources

- Soil
- Irrigation water
- · Animal manure
- Inadequately composted manure
- · Wild and domestic animals
- Inadequate field worker hygiene
- · Harvesting equipment
- Transport containers (field to packing facility)
- · Wash and rinse water
- Unsanitary handling during sorting and packaging, in packing facilities, in wholesale or retail operations, and at home
- Equipment used to soak, pack, or cut produce
- Ice
- Cooling units (hydrocoolers)
- Transport vehicles

- Improper storage conditions (temperatures)
- Improper packaging
- Cross-contamination in storage, display, and preparation

From Food Safety Begins on the Farm: A Grower's Guide (Ithaca, N.Y.: Cornell University), www.hort.cornell.edu/commercialvegetables/issues/foodsafe.html.

FOOD SAFETY IN VEGETABLE PRODUCTION

Plan Before Planting

- · Select site for produce based on land history and location.
- · Use careful manure handling.
- · Keep good records.

Field Management Considerations

- Optimize irrigation water quality and methods.
- · Avoid manure sidedressing.
- · Practice good field sanitation.
- · Exclude animals and wildlife.
- Emphasize worker training and hygiene.
- Keep records of the above activities.

From Food Safety Begins on the Farm: A Grower's Guide (Ithaca, N.Y.: Cornell University), www.hort.cornell.edu/commercialvegetables/issues/foodsafe.html.

FOOD SAFETY IN VEGETABLE HARVEST AND POSTHARVEST PRACTICES

Harvest Considerations

- Clean and sanitize storage facilities and produce contact surfaces prior to harvest.
- · Clean harvesting aids each day.
- · Emphasize worker hygiene and training.
- Emphasize hygiene to U-Pick customers.
- · Keep animals out of the fields.

Postharvest Considerations

- Enforce good worker hygiene.
- · Clean and sanitize packing area and lines daily.
- Maintain clean and fresh water.
- Cool produce quickly and maintain cold chain.
- Sanitize trucks before loading.
- · Keep animals out of packinghouse and storage facilities.

From Food Safety Begins on the Farm: A Grower's Guide (Ithaca, N.Y.: Cornell University), www.hort.cornell.edu/commercialvegetables/issues/foodsafe.html.

Human Pathogens That May Be Associated with Fresh Vegetables

- Soil-associated pathogenic bacteria (Clostridium botulinum, Listeria moncytogenes)
- Fecal-associated pathogenic bacteria (Salmonella spp., Shigella spp., E. coli O157:H7, and others)
- Pathogenic parasites (*Cryptosporidium*, *Cyclospora*)
- Pathogenic viruses (Hepatitis, Norwalk virus, and others)

Basic Principles of Good Agricultural Practices (GAPs)

- Prevention of microbial contamination of fresh produce is favored over reliance on corrective actions once contamination has occurred.
- To minimize microbial food safety hazards in fresh produce, growers
 or packers should use GAPs in those areas over which they have a
 degree of control while not increasing other risks to the food supply or
 the environment.
- Anything that comes in contact with fresh produce has the potential to contaminate it. For most foodborne pathogens associated with produce, the major source of contamination is human or animal feces.
- Whenever water comes in contact with fresh produce, its source and quality dictate the potential for contamination.
- Practices using manure or municipal biosolid wastes should be closely managed to minimize the potential for microbial contamination of fresh produce.
- Worker hygiene and sanitation practices during production, harvesting, sorting, packing, and transport play a critical role in minimizing the potential for microbial contamination of fresh produce.

- Follow all applicable local, state, and federal laws and regulations, or corresponding or similar laws. regulations, or standards for operators outside the United States for agricultural practices.
- Accountability at all levels of the agricultural environment (farms, packing facility, distribution center, and transport operation) is important to a successful food safety program. There must be qualified personnel and effective monitoring to ensure that all elements of the program function correctly and to help track produce back through the distribution channels to the producer.

Adapted from James R. Gorny and Devon Zagory, "Food Safety," in *The Commercial Storage of Fruits*, *Vegetables, and Florist and Nursery Stocks* (USDA Agriculture Handbook 66, 2004), http://www.ba.ars.usda.gov/hb66/contents.html.

TABLE 8.1. SANITIZING CHEMICALS FOR PACKINGHOUSES

| Compound | Advantages | Disadvantages |
|---|--|---|
| Chlorine (most widely used sanitizer in packinghouse water systems) | Relatively inexpensive. Broad spectrum— effective on many microbes. Practically no residue left on the commodity. | Corrosive to equipment. Sensitive to pH. Below 6.5 or above 7.5 reduces activity or increases noxious odors. Can irritate skin and |
| Chlorine Dioxide | Activity is much less pH dependent than chlorine. | damage mucous membranes. Must be generated on- site. Greater human exposure risk than chlorine. Off gassing of noxious gases is common. |
| Peroxyacetic Acid | No known toxic residues or byproducts. Produces very little off gassing. Less affected by organic matter than chlorine. Low corrosiveness to equipment. | Concentrated gases can be explosive. Activity is reduced in the presence of metal ions. Concentrated product is toxic to humans. Sensitive to pH. Greatly reduced activity at pH above 7–8. |

TABLE 8.1. SANITIZING CHEMICALS FOR PACKINGHOUSES (Continued)

| Compound | Advantages | Disadvantages |
|----------|---|---|
| Ozone | Very strong oxidizer/ sanitizer. Can reduce pesticide residues in the water. Less sensitive to pH than chlorine (but breaks down much faster above ~pH 8.5). No known toxic residues or byproducts. | Must be generated onsite. Ozone gas is toxic to humans. Off gassing can be a problem. Treated water should be filtered to remove particulates and organic matter. Corrosive to equipment (including rubber and some plastics). Highly unstable in water—half-life ~15 min; may be less than 1 min in water with organic matter or soil. |

Note: Although quaternary ammonia is an effective sanitizer with useful properties and can be used to sanitize equipment, it is not registered for contact with food.

Adapted from S. A. Sargent, M. A. Ritenour, and J. K. Brecht, "Handling, Cooling, and Sanitation Techniques for Maintaining Postharvest Quality," in *Vegetable Production Handbook* (University of Florida, 2005–2006).

TRACEABILITY OF PRODUCE IN THE UNITED STATES

Traceability has been a critical component of the produce industry for many years. Historically, the perishability of produce and the potential for deterioration during cross-country shipment demanded better recordkeeping to ensure correct payment to growers. Because produce must be packed in relatively small boxes to minimize damage, implementation of traceability has also been relatively low in cost. The industry is in a much better position to adapt to new concerns than industries where bulk sales are the norm and segregation and traceability involves new costs. Currently, two

systems of information are involved in produce. First, there are physical labels on boxes and sometimes on pallets. For general business purposes, it is important to be able to identify the product in the boxes. Various state laws require box information, and marketing orders also often require additional box information. Pallet tags are completely voluntary. Second, a paper or electronic trail allows traceback between links in the marketing chain, though each link may use a different traceability system. U.S. and Canadian produce organizations are looking at ways to promote a universal traceability system. They recommend that shipper name, pallet tag number (if available), and lot number be part of the paperwork at each link. This would effectively combine information on boxes and the paper or electronic trail. Such a system would require developing a standardized system of barcodes or other machine-readable information as well as shipper and buyer investment in machines to apply and read codes. One of the challenges to developing a compelling technical solution that all market participants would use voluntarily is to ensure that all segments of the industry can afford the costs of the new system.

Perishable Agricultural Commodities Act

Key Legislation and Dates: Perishable Agricultural Commodities Act (PACA) was enacted in 1930.

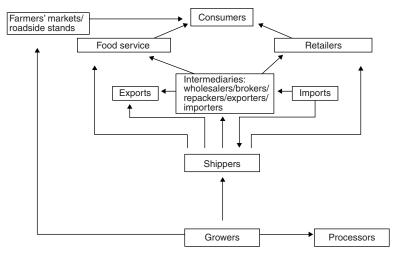


Figure 8.1. Tracing fresh produce through the food marketing system.

Objective: PACA was enacted to promote fair trading practices in the fruit and vegetable industry. The objective of the recordkeeping is to facilitate the marketing of fruit and vegetables, to verify claims, and to minimize misrepresentation of the condition of the item, particularly when long distances separate the traders.

Coverage: Fruit and vegetables.

Recordkeeping Required: PACA calls for complete and accurate recordkeeping and disclosure for shippers, brokers, and other first handlers of produce selling on behalf of growers. PACA has extensive recordkeeping requirements with respect to who buyers and sellers are, what quantities and kinds of produce is transacted, and when and how the transaction takes place. PACA regulations recognize that the varied fruit and vegetable industries have different recordkeeping needs, and the regulations allow for this variance. Records must be kept for 2 years from the closing date of the transaction.

Elise Golan et al., Traceability in the U.S. Food Supply: Economic Theory and Industry Studies (USDA ERS AER830, 2004), http://www.ers.usda.gov/publications/aer830.

02

GENERAL POSTHARVEST HANDLING PROCEDURES

Additional information on postharvest handling can be found on these websites:

Agriculture and Agri-Food Canada, www.agr.gc.ca

California Department of Food and Agriculture, www.cdfa.ca.gov

Environmental Protection Agency (EPA), Office of Pesticide Programs, www.epa.gov

Food and Agriculture Organization (FAO), Information Network on Postharvest Operations (InPhO), www.fao.org/inpho

Hawaii Agriculture Food Quality and Safety, http://www.hawaiiag.org/foodsaf.htm

Information Network on Postharvest Operations, www.fao.org/inpho

North Carolina State University Cooling and Handling Publications, http://www.bae.ncsu.edu/programs/extension/publicat/postharv/index.html

UC Davis Postharvest Technology Research and Information Center, http://postharvest.ucdavis.edu

USDA/Agricultural Marketing Service/Fruit and Vegetable Division, www.usda.gov/ams/fruitveg.htm

USDA/Economic Research Service, http://www.ers.usda.gov/

USDA Food Safety and Inspection Service, www.fsis.usda.gov

USDA National Agricultural Statistics Service, http://www.nass.usda.gov/

University of Florida Market Information System, http://marketing.ifas.ufl.edu/

University of Florida Postharvest Programs, http://postharvest.ifas.ufl.edu

TABLE 8.2. LEAFY, FLORAL, AND SUCCULENT VEGETABLES

Step Function

- 1. Harvesting mostly by hand; some harvesting aids are in use.
- 2. Transport to packinghouse and unloading if not field packed.
- 3. Cutting and trimming (by harvester or by different worker on mobile packing line or in packinghouse).
- 4. Sorting and manual sizing (as above).
- 5. Washing or rinsing.
- 6. Wrapping (e.g., cauliflower, head lettuce) or bagging (e.g., celery).
- Packing in shipping containers (waxed fiberboard or plastic to withstand water or ice exposure for cooling).
- 8. Palletization of shipping containers.
- 9. Cooling methods.
 - Vacuum cooling: lettuce
 - Hydrovacuum cooling: cauliflower, celery
 - Hydrocooling: artichoke, celery, green onion, leaf lettuce, leek, spinach
 - Package ice: broccoli, parsley, spinach
 - · Room cooling: artichoke, cabbage
- 10. Transport, destination handling, retail handling.

TABLE 8.3. UNDERGROUND STORAGE ORGAN VEGETABLES

Step Function

- Mechanical harvest (digging, lifting), except hand harvesting of sweet potato.
- 2. Curing (in field) of potato, onion, garlic, and tropical crops.
- 3. Field storage of potatoes and tropical storage organ vegetables in pits, trenches, or clamps.
- 4. Collection into containers or into bulk trailers.
- Transport to packinghouse and unloading.
- 6. Cleaning by dry brushing or with water.
- 7. Sorting to eliminate defects.
- 8. Sizing.
- Packing in bags or cartons; consumer packs placed within master containers.
- 10. Palletization of shipping containers.
- 11. Cooling methods.
 - a. Hydrocooling of temperate storage roots and tubers.
 - b. Room cooling of potato, onion, garlic, and tropical storage organs.
- 12. Curing.
 - a. Forced-air drying (onion and garlic).
 - High temperature and relative humidity (potato and tropical storage organs).
- 13. Storage.
 - a. Ventilated storage of potato, onion, garlic, and sweet potato in cellars and warehouses.
 - b. Temporary storage of temperate storage organ vegetables.
 - Long-term storage of potato, onion, garlic, and tropical crops following curing.
- 14. Fungicide treatment (sweet potato); sprout inhibitor (potato).
- 15. Transport, destination handling, retail handling.

TABLE 8.4. IMMATURE FRUIT VEGETABLES

Step Function

- Harvesting mostly by hand into buckets or trays; some harvesting aids are in use.
 - a. Sweet corn, snap bean, and pea are also harvested mechanically.
 - b. Field-packed vegetables are usually not washed, but they may be wiped with a moist cloth or spray-washed on a mobile packing line.
- For packinghouse operations, stacking buckets or trays on trailers or transferring to shallow pallet bins.
- 3. Transporting harvested vegetables to packinghouse.
- 4. Unloading by dry or wet dump.
- 5. Washing or rinsing.
- 6. Sorting to eliminate defects.
- 7. Waxing cucumber and pepper.
- 8. Sizing.
- 9. Packing in shipping containers by weight or count.
- 10. Palletizing shipping containers.
- 11. Cooling methods:
 - a. Hydrocooling: bean, pea, sweet corn.
 - Forced-air cooling: chayote, cucumber, eggplant, okra, summer squash.
 - c. Slush-ice cooling and vacuum cooling: sweet corn.
- 12. Temporary storage.
- 13. Transporting, destination handling, retail handling.

TABLE 8.5. MATURE FRUIT VEGETABLES

Step Function

- 1. Harvesting.
- 2. Hauling to the packinghouse or processing plant.
- 3. Cleaning.
- 4. Sorting to eliminate defects.
- 5. Waxing (tomato, pepper).
- 6. Sizing and sorting into grades.
- 7. Packing—shipping containers.
- 8. Palletization and unitization.
- 9a. Curing of winter squash and pumpkin.
- 9b. Ripening of melon and tomato with ethylene.
- 10. Cooling (hydrocooling, room cooling, forced-air cooling).
- 11. Temporary storage.
- 12. Loading into transport vehicles.
- 13. Destination handling (distribution centers, wholesale markets, etc.).
- 14. Delivery to retail.
- 15. Retail handling.

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03 PREDICTING HARVEST DATES AND YIELDS

TABLE 8.6. APPROXIMATE TIME FROM VEGETABLE PLANTING TO MARKET MATURITY UNDER OPTIMUM GROWING CONDITIONS

Time to Market Maturity¹ (days)

| Vegetable | Early Variety | Late Variety | Common Variety |
|-------------------------------|------------------|-----------------|-------------------|
| Bean, broad | _ | _ | 120 |
| Bean, bush | 48 | 60 | |
| Bean, edible soy | 84 | 115 | _ |
| Bean, pole | 58 | 70 | _ |
| Bean, lima, bush | 65 | 80 | _ |
| Bean, lima, pole | 80 | 88 | _ |
| Beet | 50 | 65 | _ |
| $\mathrm{Broccoli}^2$ | 60 | 85 | _ |
| Broccoli raab | _ | _ | 70 |
| Brussels sprouts ² | 90 | 120 | _ |
| Cabbage | 70 | 120 | _ |
| Cardoon | _ | _ | 120 |
| Carrot | 50 | 95 | _ |
| Cauliflower ² | 55 | 90 | _ |
| Celeriac | _ | _ | 110 |
| Celery ² | 90 | 125 | _ |
| Chard, Swiss | 50 | 60 | _ |
| Chervil | _ | _ | 60 |
| Chicory | 65 | 150 | _ |
| Chinese cabbage | 50 | 80 | _ |
| Chive | _ | _ | 90 |
| Collards | 70 | 85 | _ |
| Corn, sweet | 60 | 95 | _ |
| Corn salad | _ | _ | 60 |
| Cress | _ | _ | 45 |
| Cucumber, pickling | 48 | 58 | _ |
| Cucumber, slicing | 55 | 70 | _ |
| Dandelion | _ | _ | 85 |
| | | | |

TABLE 8.6. APPROXIMATE TIME FROM VEGETABLE PLANTING
TO MARKET MATURITY UNDER OPTIMUM GROWING
CONDITIONS (Continued)

Time to Market Maturity¹ (days)

| Vegetable | Early Variety | Late Variety | Common Variety |
|--------------------------|------------------|-----------------|-------------------|
| Eggplant ² | 60 | 80 | |
| Endive | 80 | 100 | _ |
| Florence fennel | _ | _ | 100 |
| Kale | _ | _ | 55 |
| Kohlrabi | 50 | 60 | _ |
| Leek | _ | _ | 120 |
| Lettuce, butterhead | 55 | 70 | _ |
| Lettuce, cos | 65 | 75 | _ |
| Lettuce, head | 70 | 85 | _ |
| Lettuce, leaf | 40 | 50 | _ |
| Melon, cantaloupe | 75 | 105 | |
| Melon, casaba | _ | _ | 110 |
| Melon, honeydew | 90 | 110 | _ |
| Melon, Persian | _ | _ | 110 |
| Okra | 50 | 60 | _ |
| Onion, dry | 90 | 150 | _ |
| Onion, green | 45 | 70 | _ |
| Parsley | 65 | 75 | _ |
| Parsley root | _ | _ | 90 |
| Parsnip | _ | _ | 120 |
| Pea | 56 | 75 | _ |
| Pea, edible-podded | 60 | 75 | _ |
| Pepper, hot ² | 60 | 95 | _ |
| Pepper, sweet 2 | 65 | 80 | _ |
| Potato | 90 | 120 | _ |
| Pumpkin | 85 | 120 | _ |
| Radicchio | 90 | 95 | _ |
| Radish | 22 | 30 | _ |
| Radish, winter | 50 | 65 | _ |
| Roselle | _ | _ | 175 |
| Rutabaga | _ | _ | 90 |
| | | | |

TABLE 8.6. APPROXIMATE TIME FROM VEGETABLE PLANTING TO MARKET MATURITY UNDER OPTIMUM GROWING CONDITIONS (Continued)

Time to Market Maturity¹ (days)

| Vegetable | Early Variety | Late Variety | Common Variety |
|---------------------|------------------|-----------------|-------------------|
| Salsify | _ | _ | 150 |
| Scolymus | _ | _ | 150 |
| Scorzonera | _ | _ | 150 |
| Sorrel | _ | _ | 60 |
| Southern pea | 65 | 85 | _ |
| Spinach | 37 | 45 | _ |
| Squash, summer | 40 | 50 | _ |
| Squash, winter | 80 | 120 | _ |
| Sweet potato | 120 | 150 | _ |
| Tomatillo | _ | _ | 80 |
| Tomato ² | 60 | 85 | _ |
| Tomato, processing | 118 | 130 | _ |
| Turnip | 35 | 50 | _ |
| Watercress | _ | _ | 180 |
| Watermelon | 75 | 95 | _ |

¹Maturity may vary depending on season, latitude, production practices, variety, and other factors.

² Time from transplanting. See page 63-64.

TABLE 8.7. APPROXIMATE TIME FROM POLLINATION OF VEGETABLES TO MARKET MATURITY UNDER WARM GROWING CONDITIONS

| Vegetable | Time to Market Maturity ¹ (days) |
|---|---|
| Bean | 7–10 |
| Cantaloupe | 42–46 |
| Corn, ² market | 18–23 |
| Corn, ² processing | 21-27 |
| Cucumber, pickling (¾-11/8 in. in diameter) | 4-5 |
| Cucumber, slicing | 15–18 |
| Eggplant (3/3 maximum size) | 25-40 |
| Okra | 4–6 |
| Pepper, green stage (about maximum size) | 45 - 55 |
| Pepper, red stage | 60-70 |
| Pumpkin, Connecticut Field | 80-90 |
| Pumpkin, Dickinson | 90-110 |
| Pumpkin, Small Sugar | 65–75 |
| Squash, summer, crookneck | $6-7^{3}$ |
| Squash, summer, straightneck | $5-6^{3}$ |
| Squash, summer, scallop | $4-5^{3}$ |
| Squash, summer, zucchini | $3-4^{3}$ |
| Squash, winter, banana | 70–80 |
| Squash, winter, Boston Marrow | 60-70 |
| Squash, winter, buttercup | 60–70 |
| Squash, winter, butternut | 60–70 |
| Squash, winter, Golden Delicious | 60-70 |
| Squash, winter, hubbard | 80-90 |
| Squash, winter, Table Queen or acorn | 55–60 |
| Strawberry | 25-42 |
| Tomato, mature green stage | 35–45 |
| Tomato, red ripe stage | 45–60 |
| Watermelon | 42–45 |

 $^{^{1}}$ Maturity may vary depending on season, latitude, production practices, variety, and other factors.

 $^{^2\,\}mathrm{Days}$ from 50% silking.

 $^{^3}$ For a weight of $^1/_4-^1/_2$ lb.

TABLE 8.8. ESTIMATING YIELDS OF CROPS

Predicting crop yields before the harvest aids in scheduling the harvests of various fields for total yields and allows harvesting to obtain highest yields of a particular grade or stage of maturity. To estimate yields, follow these steps:

- 1. Select and measure a typical 10-ft section of a row. If the field is variable or large, you may want to select several 10-ft sections.
- 2. Harvest the crop from the measured section or sections.
- 3. Weigh the entire sample for total yields, or grade the sample and weigh the graded sample for yield of a particular grade.
- If you have harvested more than one 10-ft section, divide the yield by the number of sections harvested.
- 5. Multiply the sample weight by the conversion factor in the table for your row spacing. The value obtained will equal hundredweight (cwt) per acre.

Conversion Factors for Estimating Yields

| Row Spacing (in.) | Multiply Sample Weight (lb) by Conversion Factor to Obtain cwt/acre | |
|-------------------|--|--|
| 12 | 43.6 | |
| 15 | 34.8 | |
| 18 | 29.0 | |
| 20 | 26.1 | |
| 21 | 24.9 | |
| 24 | 21.8 | |
| 30 | 17.4 | |
| 36 | 14.5 | |
| 40 | 13.1 | |
| 42 | 12.4 | |
| 48 | 10.9 | |

Example 1: A 10-ft sample of carrots planted in 12-in. rows yields 9 lb of No. 1 carrots.

$$9 \times 43.6 = 392.4 \text{ cwt/acre}$$

Example 2: The average yield of three 10-ft samples of No. 1 potatoes planted in 36-in. rows is 26 lb.

$$26 \times 14.5 = 377 \text{ cwt/acre}$$

TABLE 8.9. YIELDS OF VEGETABLE CROPS

| Artichoke Asparagus Bean, fresh market Bean, processing Bean, lima, processing Beet, fresh market Beet, processing Broccoli Brussels sprouts Cabbage, fresh market Cabbage, processing Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards Corn, fresh market | 125 30 62 75 25 140 320 145 | 160 45 100 135 40 200 400 200 |
|---|--|--|
| Asparagus Bean, fresh market Bean, processing Bean, lima, processing Beet, fresh market Beet, processing Broccoli Brussels sprouts Cabbage, fresh market Cabbage, processing Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 30 62 75 25 140 320 145 | 45 100 135 40 200 400 200 |
| Bean, fresh market Bean, processing Bean, lima, processing Beet, fresh market Beet, processing Broccoli Brussels sprouts Cabbage, fresh market Cabbage, processing Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 75 25 140 320 145 | 135 40 200 400 200 |
| Bean, processing Bean, lima, processing Beet, fresh market Beet, processing Broccoli Brussels sprouts Cabbage, fresh market Cabbage, processing Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 25 140 320 145 | 40 200 400 200 |
| Bean, lima, processing Beet, fresh market Beet, processing Broccoli Brussels sprouts Cabbage, fresh market Cabbage, processing Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 140 320 145 | 200 400 200 |
| Beet, fresh market Beet, processing Broccoli Brussels sprouts Cabbage, fresh market Cabbage, processing Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 320 145 | 400 200 |
| Broccoli Brussels sprouts Cabbage, fresh market Cabbage, processing Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 145 | 200 |
| Brussels sprouts Cabbage, fresh market Cabbage, processing Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | | |
| Cabbage, fresh market Cabbage, processing Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 180 | 200 |
| Cabbage, processing Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | | 200 |
| Cabbage, processing Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 320 | 450 |
| Carrot, fresh market Carrot, processing Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 500 | 800 |
| Cauliflower Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 350 | 800 |
| Celeriac Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 520 | 700 |
| Celery Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | 170 | 200 |
| Chard, Swiss Chinese cabbage, napa Chinese cabbage, pak choi Collards | _ | 200 |
| Chinese cabbage, napa Chinese cabbage, pak choi Collards | 650 | 750 |
| Chinese cabbage, pak choi Collards | _ | 150 |
| Collards | _ | 400 |
| 0 0 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 | _ | 300 |
| Corn fresh market | 120 | 200 |
| | 110 | 200 |
| Corn, processing | 150 | 200 |
| Cucumber, fresh market | 185 | 300 |
| Cucumber, processing | 110 | 300 |
| Eggplant | 250 | 350 |
| Endive, escarole | 180 | 200 |
| Garlic | 165 | 200 |
| Horseradish | _ | 80 |
| Lettuce, head | 360 | 400 |
| Lettuce, leaf | 200 | 325 |
| Lettuce, romaine | 300 | 350 |
| Melon, cantaloupe | 250 | 250 |
| Melon, honeydew | 205 | 250 |
| Melon, Persian | 130 | 160 |

TABLE 8.9. YIELDS OF VEGETABLE CROPS (Continued)

| Vegetable | Approximate Average Yield in the United States (cwt/acre) | Good Yield (cwt/acre) |
|---------------------------------|---|--------------------------|
| Okra | 60 | 150 |
| Onion | 420 | 650 |
| Pea, fresh market | 40 | 60 |
| Pea, processing (shelled) | 30 | 45 |
| Pepper, bell | 290 | 375 |
| Pepper, chile (fresh and dried) | 100 | 230 |
| Pepper, pimiento | _ | 100 |
| Potato | 315 | 400 |
| Pumpkin | 215 | 400 |
| Radish | 90 | 200 |
| Rhubarb | _ | 200 |
| Rutabaga | _ | 400 |
| Snowpea | _ | 80 |
| Southern pea | _ | 35 |
| Spinach, fresh market | 160 | 225 |
| Spinach, processing | 180 | 220 |
| Squash, summer | 160 | 300 |
| Squash, winter | _ | 400 |
| Sweet potato | 145 | 300 |
| Strawberry | 400 | 600 |
| Tomato, fresh market | 290 | 400 |
| Tomato, processing | 700 | 900 |
| Tomato, cherry | _ | 600 |
| Turnip | _ | 400 |
| Watermelon | 260 | 500 |

TABLE 8.10. STATUS OF HAND VERSUS MECHANICAL HARVEST OF VEGETABLES

| Acreage Hand Harvested (%) | Vegetable | | | | |
|----------------------------------|--|---|--|---|--|
| 76–100 | Artichoke Cauliflower Green onion Eggplant Kale Pepper Sorrel Celeriac Rutabaga Jerusalem | Asparagus Celery Collards Endive Kohlrabi Rapini Squash Ginger Salsify | Broccoli ¹ Cucumber ¹ Cress Escarole Mushroom ¹ Rhubarb ¹ Watercress Parsley root Turnip | Cabbage Lettuce Dandelion Fennel Okra Romaine Cassava Parsnip Taro ¹ | |
| 51–75 26–50 0–25 | artichoke Sweet potato Turnip greens Dry onion Beet ¹ Snap bean ¹ Pea ¹ Boniato | Mustard greens Pumpkin ¹ Carrot Sweet corn ¹ Garlic Radish | Parsley Tomato ¹ Potato ¹ Spinach ¹ Brussels sprouts ¹ | Swiss chard Lima bean ¹ Horseradish ¹ Malanga | |

Adapted from A. A. Kader (ed.), Postharvest Technology of Horticultural Crops, 2nd ed., (University of California, Division of Agriculture and Natural Resources Publication 3311, 1992).

 $^{^{\}rm 1}{\rm More}$ than 50% of the crop is processed.

04 COOLING VEGETABLES

TABLE 8.11. COMPARISON OF TYPICAL PRODUCT EFFECTS AND COST FOR COMMON COOLING METHODS

| Room | 20–100 0.1–2.0 No Low High Low No No |
|----------------|---|
| Ice | 0.1 to 0.3¹ No data Yes, unless bagged Low High Low Yes Common Rarely done |
| Water Spray | 0.3–2.0 No data Yes High² Medium Medium Yes Common No |
| Vacuum | 0.3–2.0 2.0–4.0 No None Medium High No Common |
| Hydro | 0.1–1.0 0–0.5 Yes High² Low High Yes Rarely done |
| Forced-Air | 1–10 0.1–2.0 No Low Low No No Sometimes Rarely done |
| Product Effect | Cooling Time (h) Product moisture loss (%) Water contact with product Potential for decay contamination Capital cost Energy efficiency Water-resistant packaging needed Portable Feasibility of in-line cooling |

¹Top icing can take much longer.

²Recirculated water must be constantly sanitized to minimize accumulation of decay pathogens.

Adapted from James F. Thompson, "Pre-cooling and Storage Facilities" in The Commercial Storage of Fruits, Vegetables, and Nursery Stocks (USDA Agriculture Handbook 66, 2004), http://www.ba.ars.usda.gov/hb66/contents.html.

TABLE 8.12. GENERAL COOLING METHODS FOR VEGETABLES

| Method^1 | Vegetable | Comments |
|------------------------------------|--|--|
| Room cooling | All vegetables | Too slow for most perishable commodities. Cooling rates vary extensively within loads, |
| Forced-air cooling (pressure | Strawberry, fruit-type vegetables, tubers, cauliflower | pallets, and containers. Much faster than room cooling; cooling rates uniform if properly used. Container venting and stacking requirements are critical to |
| cooling) Hydrocooling | Stems, leafy vegetables, some fruit-type vegetables | effective cooling. Very fast cooling; uniform cooling in bulk if properly used, but may vary extensively in packed shipping containers; daily cleaning and |
| Package icing | Roots, stems, some flower-type vegetables, green onion, Brussels sprouts | santiation measures essentiat, product must tolerate wetting; water-tolerant shipping containers may be needed. Fast cooling; limited to commodities that can tolerate water-ice contact; water-tolerant shipping containers are essential. |

| Commodities must have a favorable surface-to- mass ratio for effective cooling. Causes about 1% weight loss for each 10°F cooled. Adding water during cooling prevents this weight loss but equipment is more expensive, and water- tolerant shipping containers are needed. | Cooling in most available equipment is too slow and variable; generally not effective. | Slow and irregular, top-ice weight reduces net payload; water-tolerant shipping containers needed. |
|---|--|--|
| Leafy vegetables; some stem and flower- type vegetables | All vegetables | Some roots, stems, leafy vegetables, cantaloupe. |
| Vacuum cooling | Transit cooling: Mechanical refrigeration | Top icing and channel icing |

Adapted from A. A. Kader (ed.), Postharvest Technology of Horticultural Crop, 2nd ed. (University of California, Division of Agriculture and Natural Resources Publication 3311, 1992). ¹For these methods to be effective, the product must be cooled continuously until reaching the consumer.

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| SPECIFIC COOLING METHODS FOR VEGETABLES |
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| TABLE 8.13. SPECIFIC COOLING |

| | Remarks | | | Carrots can be VC. | With evap coolers, facilities should be adapted to curing. |) | |
|-------------------|-----------|--|---|----------------------|--|--------------|---|
| ation | Small | FA FA | FA FA | HC, FA HC, PI, FA | | R | FA, PI HC FA, PI FA |
| Size of Operation | Large | VC, FA VC | VC, FA, WVC VC, FA, WVC, HC | HC, PI, FA HC. PI | R w/evap coolers | нс | HC, PI HC HC, FA, PI FA, VC |
| | Vegetable | Leafy Vegetables Cabbage Iceberg lettuce | Kale, collards Leaf lettuces, spinach, endive, escarole, Chinese cabbage, pak choi, romaine Root Veretables | With tops Topped | Irish potato | Sweet potato | Stem and Flower Vegetables Artichoke Asparagus Broccoli, Brussels sprouts Cauliflower |

| | | | Should be adapted to curing. | Fruit-type vegetables are chilling sensitive, but at varying temperature. See pages 444–448. |) | | | | | | | | |
|--------------------------------------|----------|--------------------------------------|---|--|--------|-----------------------------------|--------|------------|------------------|---------------------|------------|-----------------------|--------------|
| HC, FA PI | FA | FA FA, PI | R, FA | FA, FA-EC | r F | FA, FA-EC FA, FA-EC | | FA, FA-EC | FA, FA-EC | FA, FA-EC | HC, FA, PI | FA, FA-EC | |
| HC, WVC, VC PI, HC, WVC | FA, VC | HC, FA FA, PI, VC | 8 8 | В, FA, FA-БС | | HC, FA, PI FA, R | | FA, HC | R, FA, FA-EC, VC | R, FA, FA-EC | HC, VC, PI | R, FA , FA - EC | R, FA, FA-EC |
| Celery, rhubarb Green onion, leek | Mushroom | Pod Vegetables Bean Pea | Bulb Vegetables Dry onion Garlic | Fruit-type Vegetables Cucumber, eggplant | Melons | Cantaloupe Crenshaw, honeydew, | casaba | Watermelon | Pepper | Summer squash, okra | Sweet corn | Tomatillo | Tomato |
| | | | | 197 | | | | | | | | | |

TABLE 8.13. SPECIFIC COOLING METHODS FOR VEGETABLES (Continued)

| | | peramon | |
|--|--------|----------|--------------------------|
| Vegetable | Large | Small | Remarks |
| Winter squash | 씶 | R | |
| Fresh Herbs Not packaged | HC, FA | FA, R | Can be easily damaged by |
| Packaged | FA | FA, R | water beating in fic. |
| Cactus Leaves (nopalitos) Fruit (tunas or prickly pears) | 요 요 | FA FA | |

Adapted from A. A. Kader (ed.), Postharvest Technology of Horticultural Crops, 3rd ed. (University of California, Division of Agriculture and Natural Resources R = Room Cooling, FA = Forced-air Cooling, HC = Hydrocooling, VC = Vacuum Cooling, WVC = Water Spray Vacuum Cooling, FA-EC = Forced-air Evaporative Cooling, PI = Package Icing. Publication 3311, 2002).

05 VEGETABLE STORAGE

TABLE 8.14. RELATIVE PERISHABILITY AND POTENTIAL STORAGE LIFE OF FRESH VEGETABLES IN AIR AT NEAR OPTIMUM STORAGE TEMPERATURE AND RELATIVE HUMIDITY

| | Potential Sta | orage Life (weeks) | |
|-------------------------|------------------|--------------------|-----------------|
| <2 | 2–4 | 4–8 | 8–16 |
| Asparagus | Artichoke | Beet | Garlic |
| Bean sprouts | Green bean | Carrot | Onion |
| Broccoli | Brussels sprouts | Potato (immature) | Potato (mature) |
| Cantaloupe | Cabbage | Radish | Pumpkin |
| Cauliflower | Celery | | Winter squash |
| Green onion | Eggplant | | Sweet potato |
| Leaf lettuce | Head lettuce | | Taro |
| Mushroom | Mixed melons | | Yam |
| Pea | Okra | | |
| Spinach | Pepper | | |
| Sweet corn | Summer squash | | |
| Tomato (ripe) | Tomato | | |
| Fresh-cut vegetables | (partially ripe) | | |

TABLE 8.15. RECOMMENDED TEMPERATURE AND RELATIVE HUMIDITY CONDITIONS AND APPROXIMATE STORAGE LIFE OF FRESH VEGETABLES

For more detailed information about specific commodities, go to one of the following websites:

http://www.ba.ars.usda.gov/hb66/index.html

http://postharvest.ucdavis.edu/produce/producefacts/index.shtml

| | Storag | | |
|----------------------|--|-----------------------|-----------------------------|
| Vegetable | $\begin{array}{c} \text{Temperature} \\ (^{\circ}F) \end{array}$ | Relative Humidity (%) | Approximate Storage Life |
| | 22.24 | 05 100 | 10 14 1 |
| Amaranth | 32–36 | 95–100 | 10–14 days 2–3 weeks |
| Anise | 32-36 32 | 90–95 | |
| Artichoke, globe | ~- | 95–100 | 2–3 weeks |
| Artichoke, Jerusalem | 31–32 | 90–95 | 4 months |
| Asparagus | 36 | 95–100 | 2–3 weeks |
| Bean, fava | 32 | 90–95 | 1–2 weeks |
| Bean, lima | 37–41 | 95 | 5–7 days |
| Bean, snap | 40 - 45 | 95 | 7–10 days |
| Bean, yardlong | 40 - 45 | 95 | 7–10 days |
| Beet, bunched | 32 | 98–100 | 10–14 days |
| Beet, topped | 32 | 98–100 | 4 months |
| Bitter melon | 50 – 54 | 85–90 | 2-3 weeks |
| Bok choy | 32 | 95 - 100 | 3 weeks |
| Boniato | 55-60 | 85-90 | 4–5 months |
| Broccoli | 32 | 95-100 | 10–14 days |
| Brussels sprouts | 32 | 95-100 | 3-5 weeks |
| Cabbage, early | 32 | 98-100 | 3-6 weeks |
| Cabbage, late | 32 | 95-100 | 5–6 months |
| Cabbage, Chinese | 32 | 95 - 100 | 2-3 months |
| Cactus, leaves | 41-50 | 90-95 | 2-3 weeks |
| Cactus, pear | 41 | 90-95 | 3 weeks |
| Calabaza | 50-55 | 50-70 | 2-3 months |
| Carrot, bunched | 32 | 98-100 | 10-14 days |
| Carrot, topped | 32 | 98-100 | 6–8 months |
| Cassava | 32 - 41 | 85-90 | 1–2 months |

TABLE 8.15. RECOMMENDED TEMPERATURE AND RELATIVE HUMIDITY CONDITIONS AND APPROXIMATE STORAGE LIFE OF FRESH VEGETABLES (Continued)

Storage Conditions

| Vegetable | $\begin{array}{c} \text{Temperature} \\ ({}^{\circ}F) \end{array}$ | Relative Humidity (%) | Approximate Storage Life |
|---------------------|--|-----------------------|-----------------------------|
| Cauliflower | 32 | 95–98 | 3–4 weeks |
| Celeriac | 32 | 98–100 | 6–8 months |
| Celery | 32 | 98–100 98–100 | 1–2 months |
| Chard | 32 | 95–100 | 10–14 days |
| Chayote | 45 | 85–90 | 4–6 weeks |
| Chicory, witloof | 36–38 | 95–98 | 2–4 weeks |
| Chinese broccoli | 32 | 95–100 | 10–14 days |
| Collards | 32 | 95–100 95–100 | 10–14 days |
| Cucumber, slicing | 50–54 | 85–90 | 10–14 days |
| Cucumber, pickling | 40 | 95–100 | 7 days |
| Daikon | 32–34 | 95–100 95–100 | 4 months |
| Eggplant | 50 | 90–95 | 1–2 weeks |
| Endive, escarole | 32 | 95–100 | 2–4 weeks |
| Garlic | 32 | 65-70 | 6–7 months |
| Ginger | 55 | 65 | 6 months |
| Greens, cool-season | 32 | 95–100 | 10–14 days |
| Greens, warm- | 45–50 | 95–100 | 5–7 days |
| season | 40 00 | 00 100 | o raays |
| Horseradish | 30-32 | 98-100 | 10-12 months |
| Jicama | 55-65 | 85–90 | 1–2 months |
| Kale | 32 | 95–100 | 2–3 weeks |
| Kohlrabi | 32 | 98–100 | 2–3 months |
| Leek | 32 | 95–100 | 2 months |
| Lettuce | 32 | 98–100 | 2–3 weeks |
| Malanga | 45 | 70–80 | 3 months |
| Melon | | | |
| Cantaloupe | 36-41 | 95 | 2–3 weeks |
| Casaba | 45-50 | 85–90 | 3–4 weeks |
| Crenshaw | 45–50 | 85–90 | 2–3 weeks |
| Honeydew | 41–50 | 85–90 | 3–4 weeks |
| • | | | |

TABLE 8.15. RECOMMENDED TEMPERATURE AND RELATIVE HUMIDITY CONDITIONS AND APPROXIMATE STORAGE LIFE OF FRESH VEGETABLES (Continued)

| | Storage Conditions | | |
|-----------------------------|--|-----------------------|-----------------------------|
| Vegetable | $\begin{array}{c} \text{Temperature} \\ (^{\circ}F) \end{array}$ | Relative Humidity (%) | Approximate Storage Life |
| Persian | 45–50 | 85–90 | 2–3 weeks |
| Watermelon | 50-59 | 90 | 2–3 weeks |
| Mushroom | 32 | 90 | 7–14 days |
| Mustard greens | 32 | 90–95 | 7–14 days |
| Okra | 45-50 | 90–95 | 7–10 days |
| Onion, dry | 32 | 65-70 | 1–8 months |
| Onion, green | 32 | 95-100 | 3 weeks |
| Parsley | 32 | 95-100 | 8-10 weeks |
| Parsnip | 32 | 98-100 | 4–6 months |
| Pea, English, snow, snap | 32–34 | 90–98 | 1–2 weeks |
| Pepino | 41-50 | 95 | 4 weeks |
| Pepper, chile | 41 - 50 | 85-95 | 2-3 weeks |
| Pepper, sweet | 45 - 50 | 95-98 | 2-3 weeks |
| Potato, early ¹ | 50-59 | 90-95 | 10-14 days |
| Potato, late ² | 40-54 | 95-98 | 5–10 months |
| Pumpkin | 54 - 59 | 50-70 | 2–3 months |
| Radicchio | 32 - 34 | 95-100 | 3-4 weeks |
| Radish, spring | 32 | 95-100 | 1–2 months |
| Radish, winter | 32 | 95-100 | 2–4 months |
| Rhubarb | 32 | 95-100 | 2-4 weeks |
| Rutabaga | 32 | 98-100 | 4–6 months |
| Salisfy | 32 | 95–98 | 2–4 months |
| Scorzonera | 32 - 34 | 95–98 | 6 months |
| Shallot | 32 - 36 | 65 - 70 | _ |
| Southern pea | 40 – 41 | 95 | 6–8 days |
| Spinach | 32 | 95–100 | 10–14 days |
| Sprouts | | | |
| Alfalfa | 32 | 95–100 | 7 days |
| Bean | 32 | 95 - 100 | 7–9 days |

TABLE 8.15. RECOMMENDED TEMPERATURE AND RELATIVE **HUMIDITY CONDITIONS AND APPROXIMATE** STORAGE LIFE OF FRESH VEGETABLES

Storage Conditions

(Continued)

| $\begin{array}{c} \hline \\ \text{Temperature} \\ (^{\circ}F) \end{array}$ | Relative Humidity (%) | Approximate Storage Life |
|--|-----------------------|-----------------------------|
| 32 | 95–100 | 5–7 days |

| Vegetable | (°F) | (%) | Storage Life |
|-----------------------------|---------|---------|--------------|
| | | | |
| Radish | 32 | 95-100 | 5–7 days |
| Squash, summer | 45 - 50 | 95 | 1-2 weeks |
| Squash, winter ³ | 54 - 59 | 50 - 70 | 2–3 months |
| Strawberry | 32 | 90 - 95 | 5–7 days |
| Sweet corn, | 32 | 90 - 95 | 10-14 days |
| shrunken-2 | | | |
| Sweet corn, sugary | 32 | 95 - 98 | 5–8 days |
| Sweet potato ⁴ | 55-59 | 85-95 | 4–7 months |
| Tamarillo | 37 - 40 | 85-95 | 10 weeks |
| Taro | 45 - 50 | 85-90 | 4 months |
| Tomatillo | 45 - 55 | 85-90 | 3 weeks |
| Tomato, mature | 50 - 55 | 90-95 | 2-5 weeks |
| green | | | |
| Tomato, firm ripe | 46-50 | 85-90 | 1–3 weeks |
| Turnip greens | 32 | 95-100 | 10-14 days |
| Turnip root | 32 | 95 | 4–5 months |
| Water chestnut | 32-36 | 85-90 | 2-4 months |
| Watercress | 32 | 95-100 | 2-3 weeks |
| Yam | 59 | 70–80 | 2-7 months |
| | | | |

Winter, spring, or summer-harvested potatoes are usually not stored. However, they can be held 4-5 months at 40°F if cured 4 or more days at 60-70°F before storage. Potatoes for chips should be held at 70°F or conditioned for best chip quality.

² Fall-harvested potatoes should be cured at 50-60°F and high relative humidity for 10-14 days. Storage temperatures for table stock or seed should be lowered gradually to 38-40°F. Potatoes intended for processing should be stored at 50-55°F; those stored at lower temperatures or with a high reducing sugar content should be conditioned at 70°F for 1-4 weeks or until cooking tests are satisfactory.

³Winter squash varieties differ in storage life.

⁴Sweet potatoes should be cured immediately after harvest by holding at 85°F and 90-95% relative humidity for 4-7 days.

TABLE 8.16. POSTHARVEST HANDLING OF FRESH CULINARY HERBS

Storage Conditions Relative Humidity Ethylene Temperature Approximate Herb (°F) (%) Sensitivity Storage Life Basil 50 90 High 7 days Chives 32 Medium 95 - 100Cilantro 32 - 3495 - 100High 2 weeks Dill 32 95 - 100High 1-2 weeks Epazote 32 - 4190 - 95Medium 1-2 weeks Mint 32 95 - 100High 2-3 weeks Medium 1-2 weeks Oregano 32 - 4190 - 951-2 months Parsley 32 95 - 100High Perilla 50 Medium 7 days 95 Medium 2-3 weeks Sage 32 - 5090 - 952-3 weeks Thyme 3290 - 95

TABLE 8.17. RESPIRATION RATES OF FRESH CULINARY HERBS

Respiration Rates (mg/kg/hr of CO₂)

| Herb | 32°F | $50^{\circ}\mathrm{F}$ | 68°F |
|---------------|----------|------------------------|-------|
| | | | |
| Basil | 36 | 71 | 167 |
| Chervil | 12 | 80 | 170 |
| Chinese chive | 54 | 99 | 432 |
| Chives | 22 | 110 | 540 |
| Coriander | 22 | nd | nd |
| Dill | 22 | 103 | nd |
| Fennel | 19^{1} | nd | 32 |
| Ginger | nd | nd | 6^2 |
| Ginseng | 6 | 15 | nd |
| Marjoram | 28 | 68 | nd |
| Mint | 20 | 76 | 252 |
| Oregano | 22 | 101 | 176 |
| Sage | 36 | 103 | 157 |
| Tarragon | 40 | 94 | 234 |
| Thyme | 12 | 25 | 52 |

 $\label{lem:commercial} A dapted from \textit{The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks (USDA, ARS Agriculture Handbook 66, 2004), http://www.ba.ars.usda.gov/hb66/contents.html.}$

¹ At 36°F

²At 55°F

TABLE 8.18. AVERAGE RESPIRATION RATES OF VEGETABLES AT VARIOUS TEMPERATURES

| | | н | Respiration Rate (mg/kg/hr of CO_2) | (mg/kg/hr of CC | 12) | |
|----------------------|------|------|---|------------------|------|------------------------|
| Vegetable | 32°F | 41°F | 50°F | 59°F | 68°F | $77^{\circ}\mathrm{F}$ |
| Artichoke, globe | 30 | 43 | 71 | 110 | 193 | nd^1 |
| Artichoke, Jerusalem | 10 | 12 | 19 | 20 | pu | pu |
| $Asparagus^2$ | 09 | 105 | 215 | 235 | 270 | pu |
| Bean, snap | 20 | 34 | 58 | 92 | 130 | pu |
| Bean, long | 40 | 46 | 92 | 202 | 220 | pu |
| Beet | 5 | 11 | 18 | 31 | 09 | pu |
| Broccoli | 21 | 34 | 81 | 170 | 300 | pu |
| Brussels sprouts | 40 | 70 | 147 | 200 | 276 | pu |
| Cabbage | 5 | 11 | 18 | 28 | 42 | 62 |
| Cabbage, Chinese | 10 | 12 | 18 | 26 | 39 | pu |
| Carrot, topped | 15 | 20 | 31 | 40 | 25 | pu |
| Cauliflower | 17 | 21 | 34 | 46 | 42 | 92 |
| Celeriac | 7 | 13 | 23 | 35 | 45 | pu |
| Celery | 15 | 20 | 31 | 40 | 71 | pu |
| Chicory | က | 9 | 13 | 21 | 37 | pu |
| Cucumber | pu | pu | 26 | 29 | 31 | 37 |
| Eggplant, American | pu | pu | pu | .69 ³ | pu | pu |
| Eggplant, Japanese | pu | pu | pu | 131^3 | pu | pu |

| Eggplant, white egg | pu | pu | pu | 113^3 | pu | pu |
|---------------------|----|----------|--------|---------|-----|-----|
| Endive | 45 | 52 | 73 | 100 | 133 | 200 |
| Garlic | 80 | 16 | 24 | 22 | 20 | pu |
| Jicama | 9 | 11 | 14 | pu | 9 | pu |
| Kohlrabi | 10 | 16 | 31 | 46 | pu | pu |
| Leek | 15 | 25 | 09 | 96 | 110 | 115 |
| Lettuce, head | 12 | 17 | 31 | 39 | 26 | 82 |
| Lettuce, leaf | 23 | 30 | 39 | 63 | 101 | 147 |
| Luffa | 14 | 27 | 36 | 63 | 42 | pu |
| Melon | | | | | | |
| Cantaloupe | 9 | 10 | 15 | 37 | 55 | 29 |
| Honeydew | pu | ∞ | 14 | 24 | 30 | 33 |
| Watermelon | pu | 4 | 8 | pu | 21 | pu |
| Mushroom | 35 | 20 | 26 | pu | 264 | pu |
| Nopalito | pu | 18 | 40 | 26 | 74 | pu |
| Okra | pu | 40 | 91 | 146 | 261 | 345 |
| Onion, dry | က | 5 | 7 | 7 | 8 | pu |
| Pak choi | 9 | 11 | 20 | 39 | 26 | pu |
| Parsley | 30 | 09 | 114 | 150 | 199 | 274 |
| Parsnip | 12 | 13 | 22 | 37 | pu | pu |
| Pea, English | 38 | 64 | 98 | 175 | 271 | 313 |
| Pea, edible-podded | 39 | 64 | 68 | 176 | 273 | pu |
| Pepper | pu | 7 | 12 | 27 | 34 | pu |
| Potato, cured | pu | 12 | 16 | 17 | 22 | pu |
| Prickly pear | pu | pu | pu | pu | 32 | pu |
| Radicchio | 80 | 13^{4} | 23^5 | pu | pu | 45 |
| Radish, topped | 16 | 20 | 34 | 74 | 130 | 172 |
| Radish, with tops | 9 | 10 | 16 | 32 | 51 | 75 |
| Rhubarb | 11 | 15 | 25 | 40 | 49 | pu |
| Rutabaga | 5 | 10 | 14 | 26 | 37 | pu |

AVERAGE RESPIRATION RATES OF VEGETABLES AT VARIOUS TEMPERATURES (Continued) **TABLE 8.18.**

| | | Н | Respiration Rate (mg/kg/hr of CO ₂) | (mg/kg/hr of CC | O_2) | |
|--------------------|--------|------|---|-----------------|---------|------------------------|
| Vegetable | 32°F | 41°F | $50^{\circ}\mathrm{F}$ | 59°F | 68°F | $77^{\circ}\mathrm{F}$ |
| Salsify | 25 | 43 | 49 | pu | 193 | pu |
| Spinach | 21 | 45 | 110 | 179 | 230 | pu |
| Squash, summer | 25 | 32 | 29 | 153 | 164 | pu |
| Sweet corn | 41 | 63 | 105 | 159 | 261 | 359 |
| Swiss chard | 19^6 | pu | pu | pu | 29 | pu |
| Southern pea, pods | 24^6 | 25 | pu | pu | 148 | pu |
| Southern pea, peas | 29^6 | pu | pu | pu | 126 | pu |
| Tomatillo | pu | 13 | 16 | pu | 32 | pu |
| Tomato | pu | pu | 15 | 22 | 35 | 43 |
| Turnip, topped | œ | 10 | 16 | 23 | 25 | pu |
| Watercress | 22 | 50 | 110 | 175 | 322 | 377 |

Adapted from The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks (USDA Agriculture Handbook 66, 2004), http:// www.ba.ars.usda.gov/hb66/contents.html.

¹Not determined

²1 day after harvest

 $^{^3}$ At 55° F

⁴At 43°F ⁵At 45°F ⁶At 36°F

TABLE 8.19. RECOMMENDED CONTROLLED ATMOSPHERE OR MODIFIED ATMOSPHERE CONDITIONS DURING TRANSPORT AND/OR STORAGE OF SELECTED VEGETABLES

| | Temperatu | re ¹ (°F) | Atmo | crolled sphere ² %) | |
|--------------------------|-----------|-----------|----------------|--------------------------------------|-------------|
| Vegetable | Optimum | Range | O_2 | CO_2 | Application |
| Artichoke | 32 | 32-41 | 2-3 | 2–3 | Moderate |
| Asparagus | 36 | 34 - 41 | air | 10-14 | High |
| Bean, green | 46 | 41 - 50 | 2-3 | 4-7 | Slight |
| Bean, processing | 46 | 41 - 50 | 8 - 10 | 20 - 30 | Moderate |
| Broccoli | 32 | 32 - 41 | 1-2 | 5-10 | High |
| Brussels sprouts | 32 | 32 - 41 | 1-2 | 5-7 | Slight |
| Cabbage | 32 | 32 - 41 | 2-3 | 3-6 | High |
| Cantaloupe | 37 | 36 - 41 | 3-5 | 10 - 20 | Moderate |
| Cauliflower | 32 | 32 - 41 | 2-3 | 3-4 | Slight |
| Celeriac | 32 | 32 - 41 | 2-4 | 2-3 | Slight |
| Celery | 32 | 32 - 41 | 1-4 | 3-5 | Slight |
| Chinese cabbage | 32 | 32 - 41 | 1-2 | 0-5 | Slight |
| Cucumber, slicing | 54 | 46 - 54 | 1-4 | 0 | Slight |
| Cucumber, processing | 39 | 34 - 39 | 3-5 | 3-5 | Slight |
| Herbs ³ | 34 | 32 - 41 | 5-10 | 4-6 | Moderate |
| Leek | 32 | 32 - 41 | 1-2 | 2-5 | Slight |
| Lettuce, crisphead | 32 | 32 - 41 | 1-3 | 0 | Moderate |
| Lettuce, cut or shredded | 32 | 32 - 41 | 1-5 | 5 - 20 | High |
| Lettuce, leaf | 32 | 32 - 41 | 1 - 3 | 0 | Moderate |
| Mushroom | 32 | 32 - 41 | 3-21 | 5-15 | Moderate |
| Okra | 50 | 45 - 54 | air | 4-10 | Slight |
| Onion, dry | 32 | 32 - 41 | 1-2 | 0 - 10 | Slight |
| Onion, green | 32 | 32 - 41 | 2-3 | 0-5 | Slight |
| Parsley | 32 | 32 - 41 | 8 - 10 | 8 - 10 | Slight |
| Pea, sugar | 32 | 32 - 50 | 2-3 | 2-3 | Slight |
| Pepper, bell | 46 | 41 - 54 | 2-5 | 2-5 | Slight |
| Pepper, chile | 46 | 41 - 54 | 3-5 | 0-5 | Slight |
| Pepper, processing | 41 | 41 - 54 | 3-5 | 10 - 20 | Moderate |
| Radish, topped | 32 | 32 - 41 | 1-2 | 2-3 | Slight |

TABLE 8.19. RECOMMENDED CONTROLLED ATMOSPHERE OR MODIFIED ATMOSPHERE CONDITIONS DURING TRANSPORT AND/OR STORAGE OF SELECTED VEGETABLES (Continued)

| | Temperatu | re ¹ (°F) | Atmos | rolled sphere ² %) | |
|--|----------------------------|---|----------------------------------|-------------------------------------|--|
| Vegetable | Optimum | Range | ${\rm O}_2$ | CO_2 | Application |
| Spinach Sweet corn Tomato, mature, green Tomato ripe Witloof chicory | 32 32 54 50 32 | 32–41 32–41 54–59 50–59 32–41 | 7-10 2-4 3-5 3-5 3-4 | 5-10 5-10 3-5 3-5 4-5 | Slight Slight Moderate Moderate Slight |

 $^{^1\}mbox{Usual}$ and/or recommended range. A relative humidity of 90–98% is recommended.

² Specific CA recommendations depend on varieties, temperature, and duration of storage.

³ Herbs: chervil, chives, coriander, dill, sorrel, and watercress.

TABLE 8.20. OPTIMUM CONDITIONS FOR CURING ROOT, TUBER, AND BULB VEGETABLES PRIOR TO STORAGE

| Vegetable | Temperature (°F) | RH (%) | Duration (days) |
|------------------|----------------------|----------|---------------------------|
| Cassava | 86–95 | 85–90 | 4–7 |
| Malanga | 86–95 | 90-95 | 7 |
| Potato | | | |
| Early crop | 59-68 | 90 - 95 | 4-5 |
| Late crop | 50-59 | 90 - 95 | 10-15 |
| Sweet potato | 84-90 | 80-90 | 4–7 |
| Taro | 93-97 | 95 | 5 |
| Water chestnut | 86-90 | 95 - 100 | 3 |
| Yam | 86-95 | 85 - 95 | 4–7 |
| Garlic and onion | ambient (75–90 best) | | 5–10 (field drying) |
| | 93–113 | 60 - 75 | 0.5–3 (forced heated air) |

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TABLE 8.21. EFFECT OF TEMPERATURE ON THE RATE OF DETERIORATION OF VEGETABLES NOT SENSITIVE TO CHILLING INJURY

Temperature (T)

| (°F) | $ \begin{array}{c} Assumed \\ {Q_{10}}^1 \end{array} $ | Relative Rate of Deterioration | Relative Shelf Life | Loss per Day (%) |
|------|--|--------------------------------|------------------------|------------------|
| 32 | | 1.0 | 100 | 1 |
| 50 | 3.0 | 3.0 | 33 | 3 |
| 68 | 2.5 | 7.5 | 13 | 8 |
| 86 | 2.0 | 15.0 | 7 | 14 |
| 104 | 1.5 | 22.5 | 4 | 25 |

 $^{^{1}}Q_{10} = \frac{rate~of~deterioration~at~T + 10^{\circ}C}{rate~of~deterioration~at~T}$

TABLE 8.22. MOISTURE LOSS FROM VEGETABLES

| High | Medium | Low |
|---------------------|---------------------------|---------------|
| Broccoli | Artichoke | Eggplant |
| Cantaloupe | Asparagus | Garlic |
| Chard | Bean, snap | Ginger |
| Green onion | Beet^1 | Melons |
| Kohlrabi | Brussels sprouts | Onion |
| Leafy greens | Cabbage | Potato |
| Mushroom | Carrot^1 | Pumpkin |
| Oriental vegetables | $Cassava^2$ | Winter squash |
| Parsley | Cauliflower | |
| Strawberry | $Celeriac^1$ | |
| | Celery | |
| | Sweet corn ³ | |
| | ${ m Cucumber}^2$ | |
| | Endive | |
| | Escarole | |
| | Leek | |
| | Lettuce | |
| | Okra | |
| | $Parsnip^1$ | |
| | Pea | |
| | Pepper | |
| | $\mathrm{Radish^1}$ | |
| | $\mathrm{Rutabaga}^{1,2}$ | |
| | Sweet potato | |
| | Summer squash | |
| | Tomato ² | |
| | Yam | |

 $\label{eq:Adapted from B. M. McGregor, Tropical Products\ Transport\ Handbook,\ USDA\ Agricultural\ Handbook\ 668\ (1987).$

 $^{^{1} \, \}text{Root}$ crops with tops have a high rate of moisture loss.

 $^{^{2}}$ Waxing reduces the rate of moisture loss.

³ Husk removal reduces water loss.

TABLE 8.23. STORAGE SPROUT INHIBITORS

Sprout inhibitors are most effective when used in conjunction with good storage; their use cannot substitute for poor storage or poor storage management. However, storage temperatures may be somewhat higher when sprout inhibitors are used than when they are not. Follow label directions.

| Vegetable | Material | Application |
|--|---------------------|---|
| Potato (do not use on seed potatoes) | Maleic hydrazide | When most tubers are 1½-2 in. in diameter. Vines must remain green for several weeks after application. |
| | Chlorprophan (CIPC) | In storage, 2–3 weeks after harvest as an aerosol treatment. Do not store seed potatoes in a treated storage. |
| | | During washing, as an emulsifiable concentrate added to wash water to prevent sprouting during marketing. |
| Onion | Maleic hydrazide | Apply when 50% of the tops are down, the bulbs are mature, the necks soft, and 5–8 leaves are still green. |

CHILLING AND ETHYLENE INJURY

TABLE 8.24. SUSCEPTIBILITY OF VEGETABLES TO CHILLING INJURY

| Vegetable | Approximate Lowest Safe Temperature (°F) | Appearance When Stored Between 32°F and Safe Temperature ¹ |
|------------|---|---|
| Asparagus | 32–36 | Dull, gray-green, and limp tips |
| Bean, lima | 34-40 | Rusty brown specks, spots, or areas |
| Bean, snap | 45 | Pitting and russeting |
| Chayote | 41-50 | Dull brown discoloration, pitting, flesh darkening |
| Cucumber | 45 | Pitting, water-soaked spots, decay |
| Eggplant | 45 | Surface scald, alternaria rot, blackening of seeds |
| Ginger | 45 | Softening, tissue breakdown, decay |
| Jicama | 55–65 | Surface decay, discoloration |
| Melon | | |
| Cantaloupe | 36 - 41 | Pitting, surface decay |
| Casaba | 45-50 | Pitting, surface decay, failure to ripen |
| Crenshaw | 45-50 | Pitting, surface decay, failure to ripen |
| Honeydew | 45-50 | Reddish tan discoloration, pitting, surface decay, failure to ripen |
| Persian | 45-50 | Pitting, surface decay, failure to ripen |
| Watermelon | 40 | Pitting, objectionable flavor |
| Okra | 45 | Discoloration, water-soaked areas, pitting, decay |
| | | |

| Sheet pitting, alternaria rot on fruit and calyx, darkening of seed Mahogany browning, sweetening | Decay, especially alternaria rot | Decay, pitting, hard core when cooked | Surface pitting, discoloration | Internal browning, decay | Watersoaking and softening, decay | Poor color when ripe, alternaria rot |
|---|----------------------------------|---------------------------------------|--------------------------------|--------------------------|-----------------------------------|--------------------------------------|
| 45 38 | 50 | 55 | 37 - 40 | 50 | 45-50 | 55 |
| Pepper, sweet Potato | Pumpkin and hard-shell squash | Sweet potato | Tamarillo | Taro | Tomato, ripe | Tomato, mature, green |

Adapted from Chien Yi Wang, "Chilling and Freezing Injury," in The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stock (USDA Agriculture Handbook 66, 2004), http://www.ba.ars.usda.gov/hb66/index.html. ¹Severity of injury is related to temperature and time.

TABLE 8.25. VEGETABLES CLASSIFIED ACCORDING TO CHILLING INJURY SUSCEPTIBILITY

| Not Susceptible to Chilling Injury | Susceptible to Chilling Injury |
|---------------------------------------|-----------------------------------|
| Artichoke Asparagus | Bean, snap Cantaloupe |
| Bean, lima | Cantaloupe |
| Beet. | Cucumber |
| Broccoli | Eggplant |
| Brussels sprouts | Ginger |
| Cabbage | Okra |
| Carrot | Pepper |
| Cauliflower | Pepino |
| Celery | Prickly pear |
| Endive | Pumpkin |
| Garlic | Squash |
| Lettuce | Sweet potato |
| Mushroom | Tamarillo |
| Onion | Taro |
| Parsley | Tomato |
| Parsnip | Watermelon |
| Pea | Yam |
| Radish | |
| Spinach | |
| Strawberry | |
| Sweet corn | |
| Turnip | |

TABLE 8.26. RELATIVE SUSCEPTIBILITY OF VEGETABLES TO CHILLING INJURY

| Most Susceptible | Moderately Susceptible | Least Susceptible |
|---|---|---|
| Asparagus Bean, snap Cucumber Eggplant Lettuce Okra Pepper, sweet Potato Squash, summer Sweet potato Tomato | Broccoli Carrot Cauliflower Celery Onion, dry Parsley Pea Radish Spinach Squash, winter | Beet Brussels sprouts Cabbage, mature and savoy Kale Kohlrabi Parsnip Rutabaga Salsify Turnip |

Adapted from Chien Yi Wang, "Chilling and Freezing Injury," in *The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks* (USDA, Agriculture Handbook 66, 2004), http://www.ba.ars.usda.gov/hb66/index.html.

TABLE 8.27. CHILLING THRESHOLD TEMPERATURES AND VISUAL SYMPTOMS OF CHILLING INJURY FOR SOME SUBTROPICAL AND TROPICAL STORAGE ORGAN VEGETABLES

| Vegetable | Chilling Threshold (°F) | Symptoms |
|--------------|----------------------------|---|
| Cassava | 41–46 | Internal breakdown, increased water loss, failure to sprout, increased decay, loss of eating quality |
| Ginger | 54 | Accelerated softening and shriveling, oozes moisture from the surface, decay |
| Jicama | 55–59 | External decay, rubbery and translucent flesh with grown discoloration, increased water loss |
| Malanga | 45 | Tissue breakdown and internal discoloration, increased water loss, increased decay, undesirable flavor changes |
| Potato | 39 | Mahogany browning, reddish-brown areas in the flesh, adverse effects on cooking quality |
| Sweet potato | 54 | Internal brown-black discoloration, adverse effects on cooled quality, hard core, accelerated decay |
| Taro | 45–50 | Tissue breakdown and internal discoloration, increased water loss, increased decay, undesirable flavor changes |
| Yam | 55 | Tissue softening, internal discoloration (grayish flecked with reddish brown), shriveling, decay |

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TABLE 8.28. SYMPTOMS OF FREEZING INJURY ON SOME VEGETABLES

| Vegetable | Symptoms |
|-----------------|---|
| Artichoke | Epidermis becomes detached and forms whitish to light tan blisters. When blisters are broken, underlying tissue turns brown. |
| Asparagus | Tip becomes limp and dark; the rest of the spear is water- soaked. Thawed spears become mushy. |
| Beet | External and internal water-soaking and, sometimes, blackening of conducting tissue. |
| Broccoli | The youngest florets in the center of the curd are most sensitive to freezing injury. They turn brown and give strong off-odors on thawing. |
| Cabbage | Leaves become water-soaked, translucent, and limp on thawing; separated epidermis. |
| Carrot | A blistered appearance; jagged lengthwise cracks. Interior becomes water-soaked and darkened on thawing. |
| Cauliflower | Curds turn brown and have a strong off-odor when cooked. |
| Celery | Leaves and petioles appear wilted and water-soaked on thawing. Petioles freeze more readily than leaves. |
| Garlic | Thawed cloves appear water-soaked, grayish yellow. |
| Lettuce | Blistering, dead cells of the separated epidermis on outer leaves become tan; increased susceptibility to physical damage and decay. |
| Onion | Thawed bulbs are soft, grayish yellow, and water-soaked in cross section; often limited to individual scales. |
| Pepper, bell | Dead, water-soaked tissue in part of or all pericarp surface; pitting, shriveling, decay follow thawing. |
| Potato | Freezing injury may not be externally evident but shows as gray or bluish gray patches beneath the skin. Thawed tubers become soft and watery. |
| Radish | Thawed tissues appear translucent; roots soften and shrivel. |
| Sweet potato | A yellowish brown discoloration of the vascular ring, and a yellowish green water-soaked appearance of other tissues. Roots soften and become susceptible to decay. |
| Tomato | Water-soaked and soft on thawing. In partially frozen fruits, the margin between healthy and dead tissue is distinct, especially in green fruits. |
| Turnip | Small water-soaked spots or pitting on the surface. Injured tissues appear tan or gray and give off an objectionable odor. |

 $\label{lem:A.A. Kader, J. M. Lyons, and L. L. Morris, "Postharvest Responses of Vegetables to Preharvest Field Temperature," \\ \textit{HortScience 9} \ (1974):523-527.$

TABLE 8.29. SOME POSTHARVEST PHYSIOLOGICAL DISORDERS OF VEGETABLES, ATTRIBUTABLE DIRECTLY OR INDIRECTLY TO PREHARVEST FIELD TEMPERATURES

| Vegetable | Disorder | Symptoms and Development |
|---------------------|------------------------|---|
| Asparagus | Feathering | Bracts of the spears are partly spread as a result of high temperature. |
| Brussels sprouts | Black leaf speck | Becomes visible after storage for 1–2 weeks at low temperature. Has been attributed in part to cauliflower mosaic virus infection in the field, which is influenced by temperature and other environmental factors. |
| | Tip burn | Leaf margins turn light tan to dark brown. |
| Cantaloupe | Vein tract browning | Discoloration of unnetted longitudinal stripes; related partly to high temperature and virus diseases. |
| Garlic | Waxy breakdown | Enhanced by high temperature during growth; slightly sunken, light yellow areas in fleshy cloves, then the entire clove becomes amber, slightly translucent, and waxy but still firm. |
| Lettuce | Tip burn | Light tan to dark brown margins of leaves. Has been attributed to several causes, including field temperature; it can lead to soft rot development during postharvest handling. |
| | Rib discoloration | More common in lettuce grown when day temperatures exceed 81°F or when night temperatures are between 55–64°F than in lettuce grown during cooler periods. |
| | Russet spotting | Small tan, brown, or olive spots randomly distributed over the affected leaf; a postharvest disorder of lettuce induced by ethylene. Lettuce is more susceptible to russet spotting when harvested after high field temperatures (above 86°F) for 2 days or more during the 10 days before harvest. |

TABLE 8.29. SOME POSTHARVEST PHYSIOLOGICAL DISORDERS OF VEGETABLES, ATTRIBUTABLE DIRECTLY OR INDIRECTLY TO PREHARVEST FIELD TEMPERATURES (Continued)

| Vegetable | Disorder | Symptoms and Development |
|-----------|------------------------------|---|
| | Rusty brown discoloration | Rusty brown discoloration has been related to internal rib necrosis associated with lettuce mosaic virus infection, which is influenced by field temperature and other environmental factors. |
| Onion | Translucent scale | Grayish water-soaked appearance of the outer two or three fleshy scales of the bulb; translucency makes venation distinct. In severe cases, the entire bulb softens, and off-odors may develop. |
| Potato | Blackheart | May occur in the field during excessively hot weather in waterlogged soils. Internal symptom is dark gray to purplish or black discoloration, usually in the center of the tuber. |
| Radish | Pithiness | Textured white spots or streaks in cross section, large air spaces near the center, tough and dry roots. Results from high temperature. |

Adapted from A. A. Kader, J. M. Lyons, and L. L. Morris, "Postharvest Responses of Vegetables to Preharvest Field Temperature," *HortScience* 9 (1974):523–527.

TABLE 8.30. SYMPTOMS OF SOLAR INJURY ON SOME VEGETABLES

| Vegetable | Symptoms |
|------------------|--|
| Bean, snap | Very small brown or reddish spots on one side of the pod coalesce and become water-soaked and slightly shrunken. |
| Cabbage | Blistering of some outer leaves leads to a bleached, papery appearance. Desiccated leaves are susceptible to decay. |
| Cauliflower | Discoloration of curds from yellow to brown to black (solar browning). |
| Cantaloupe | Sunburn: dry, sunken, and white to light tan areas. In milder sunburn, ground color is green or spotty brown. |
| Lettuce | Papery areas on leaves, especially the cap leaf, develop during clear weather when air temperatures are higher than 77°F; affected areas become focus for decay. |
| Honeydew melon | White to gray area at or near the top, may be slightly wrinkled, undesirable flavor, or brown blotch, which is tan to brown discolored areas caused by death of epidermal cells due to excessive ultraviolet radiation. |
| Onion and garlic | Sunburn: dry scales are wrinkled, sometimes extending to one or two fleshy scales. Injured area may be bleached depending on the color of the bulb. |
| Pepper, bell | Dry and papery areas, yellowing, and, sometimes, wilting. |
| Potato | Sunscald: water and blistered areas on the tuber surface. Injured areas become sunken and leathery, and subsurface tissue rapidly turns dark brown to black when exposed to air. |
| Tomato | Sunburn (solar yellowing): affected areas on the fruit become whitish, translucent, thin-walled, a netted appearance may develop. Mild solar injury may not be noticeable at harvest but becomes more apparent after harvest as uneven ripening. |

Adapted from A. A. Kader, J. M. Lyons, and L. L. Morris, "Postharvest Responses of Vegetables to Preharvest Field Temperature," HortScience 9 (1974):523–527.

TABLE 8.31. CLASSIFICATION OF HORTICULTURAL COMMODITIES ACCORDING TO ETHYLENE PRODUCTION RATES

| Very Low | Low | Moderate | High | Very High |
|------------------|--------------|-------------------|----------------------|---------------|
| Artichoke | Blackberry | Banana | Apple | Cherimoya |
| Asparagus | Blueberry | Fig | Apricot | Mammee apple |
| Cauliflower | Casaba melon | Guava | Avocado | Passion fruit |
| Cherry | Cranberry | Honeydew melon | Cantaloupe | Sapote |
| Citrus | Cucumber | Mango | Feijoa | |
| Grape | Eggplant | Plantain | Kiwi fruit (ripe) | |
| Jujube | Okra | Tomato | Nectarine | |
| Leafy vegetables | Olive | | Papaya | |
| Most cut flowers | Pepper | | Peach | |
| Pomegranate | Persimmon | | Pear | |
| Potato | Pineapple | | Plum | |
| Root vegetables | Pumpkin | | | |
| Strawberry | Raspberry | | | |
| · | Tamarillo | | | |
| | Watermelon | | | |

COMPATIBILITY OF FRESH PRODUCE IN MIXED LOADS UNDER VARIOUS RECOMMENDED TRANSIT CONDITIONS

Shippers and receivers of fresh fruits and vegetables frequently prefer to handle shipments that consist of more than one commodity. In mixed loads, it is important to combine only those commodities that are compatible in their requirements for temperature, modified atmosphere, relative humidity, protection from odors, and protection from physiologically active gases such as ethylene.

TABLE 8.32. RECOMMENDED TRANSIT CONDITIONS FOR COMPATIBLE GROUPS

| Temp.: 55–60°F; Relative humidity: 85–95%; Ice: No contact with commodity | Temp.: 36–41°F; Relative humidity: 90–95%; Ice: Contact cantaloupe only | Temp.: 36–41°F; Temp.: 40–45°F; Temp.: 40–55°F; Relative humidity: 90–95%; Relative humidity: about 95%; Relative humidity: 85–90%; Ice: Contact cantaloupe Ice: No contact with commodity commodity | Temp.: 40–55°F; Relative humidity: 85–90%; Ice: No contact with commodity |
|--|--|--|---|
| Avocado Banana Grapefruit (AZ and CA; FL before Jan 1) | Cranberry Lemon Cantaloupe | Snap bean Lychee Okra | Cucumber Eggplant Ginger (not with eggplant) |
| Guava | Orange | Pepper, green (not with bean) Grapefruit (Fla. after Jan. 1: and Tex) | Grapefruit (Fla. after Jan. 1: and Tex) |
| Mango Casaba melon Crenshaw melon Honeydew melon Persian melon Olive Papaya Pineapple (not with avocado) Tomato, green Tomato, pink Watermelon | Tangerine | Pepper, red Summer squash Tomato, pink Watermelon | Lime Potato Pumpkin Watermelon Winter squash |

TABLE 8.32. RECOMMENDED TRANSIT CONDITIONS FOR COMPATIBLE GROUPS (Continued)

| Temp.: 32–34°F; Relative humidity: 95–100%; Ice: No contact with asparagus, fig, grape, mushroom | Temp.: 32–34°F; Relative humidity: 95– 100%; Ice: Contact with all commodities | Temp.: 55–65°F; Relative humidity: 85–90%; Ice: No contact with any commodity | Temp.: 32–34°F; Relative humidity: 65–75%; Ice: No contact with any commodity |
|---|--|--|--|
| Artichoke Asparagus Beet Carrot Endive, escarole Fig Grape Greens Leek (not with fig or grape) Parsley Parsley Parslity Spinach Salsify Sweet corn Watercress | Broccoli Brussels sprouts Cabbage Cauliflower Celeriac Celery Horseradish Kohlrabi Onion, green (not with rhubarb, fig, or grape; probably not with mushroom or sweet corn) Radish Rutabaga Turnip | Ginger Sweet potato | Garlic Onion, dry |
| | | | |

Adapted from W. J. Lipton, Compatibility of Fruits and Vegetables During Transport in Mixed Loads, USDA, ARS, Marketing Research Report 1070 (1977).

TABLE 8.33. COMPATIBLE FRESH FRUITS AND VEGETABLES DURING 10-DAY STORAGE

GROUP 1A $(32^{\circ}-36^{\circ})$ AND 90-98% RH VEGETABLES

| Alfalfa sprouts | $Cabbage^1$ | Endive. 1 chicory | $Lettuce^1$ | Rhubarb |
|-------------------------------|------------------------------|--------------------------------|-----------------------|----------------------------|
| | $Carrot^1$ | $Escarole^{1}$ | Mint^1 | Salsify |
| | $Cauliflower^1$ | $Fennel^1$ | $\mathrm{Mushroom}^1$ | Scorzonera |
| $Artichoke^1$ | Celeriac | Garlic | $Mustard greens^1$ | $Shallot^1$ |
| | $Celery^1$ | $Green onion^1$ | $Pak choi^1$ | Snow pea 1 |
| ı, lima | $Chard^1$ | Herbs ¹ (not basil) | $Parsley^1$ | $Spinach^1$ |
| Bean sprouts | Chinese cabbage ¹ | Horseradish | $Parsnip^1$ | Swiss $chard^1$ |
| | Chinese turnip | Jerusalem artichoke | Pea^1 | Turnip |
| Belgian endive ¹ | $Collards^1$ | Kailon | $ m Radicchio^1$ | Turnip greens ¹ |
| $ m er^1$ | Corn: sweet, baby | Kale^1 | Radish | Water chestnut |
| | Cut vegetables | Kohlrabi | Rutabaga | $Watercress^1$ |
| Brussels sprouts ¹ | $Daikon^1$ | Leek^1 | | |

GROUP 1B $(32^{\circ}-36^{\circ})$ AND 85-95% RH FRUITS AND MELONS

| Apple Caimito Da Apricot Cantaloupe De Avocado, ripe Cashew apple El Barbados cherry Coconut Galueberry Currant Galueberry Galueberry Carrant Carran | Date Dewberry Elderberry Fig Gooseberry Grape | Loganberry Longan Loquat Pear: Asian, European Persimmon ¹ | Plumcot Pomegranate Prune Quince Raspberry Strawberry |
|--|--|---|---|
| Cut fruits | $	ilde{	ext{Kiwifruit}}^1$ | | . |

TABLE 8.33. COMPATIBLE FRESH FRUITS AND VEGETABLES DURING 10-DAY STORAGE (Continued)

| GROUP 2 (55°–6 VEGETABLES | GROUP 2 (55°–65°) AND 85–95% RH VEGETABLES | | FRUITS AND MELONS | TONS | |
|--|---|---|---|--|---|
| Beans: snap, green, wax Cactus leaves (nopales) ¹ Calabaza Chayote ¹ Cucumber ¹ Eggplant ¹ Kiwano (horned melon) | | Long bean Malanga¹ Pepper: bell, chili Southern pea Squash: summer¹ Tomatillo | Babaco Calamondin Carambola Cranberry Custard apple Durian Feijoa Granadilla | Juan canary melon Lemon¹ Lime¹ Limequat Mandarin Olive Orange Passion fruit | Pepino Pummelo Tamarillo Tamarind Tangelo Tangelo Ugli fruit Watermelon |
| GROUP 3 (55°–6 VEGETABLES | GROUP 3 (55°–65°) AND 85–95% RH VEGETABLES | FRU | FRUITS AND MELONS | | |
| $\begin{array}{c} \text{Bitter melon} \\ \text{Boniato}^1 \end{array}$ | Potato Pumpkin | Atemoya Banana | Atemoya Banana | Honeydew melon Jaboticaba | Persian melon Plantain |
| Cassava Dry onion Ginger Jicama | Squash: winter ¹ Sweet potato ¹ Taro (dasheen) Yam | Breadfru Canistel Casaba 1 Cherimo | Breadfruit Canistel Casaba melon Cherimoya | Jackfruit Mamey sapote Mango Mangosteen | Rambutan Sapodilla Sapote Soursop |
| orcania | TOTAL | | imoya | Mailgosteri | Joseph |

Adapted from A. A. Kader (ed.), Postharvest Technology of Horticultural Crops, 3rd ed. (University of California. Division of Agriculture and Natural Resources Publications 3311, 2002).

Papaya

Crenshaw melon

Note: Ethylene level should be kept below 1 ppm in storage areas.

¹Products sensitive to ethylene damage.

07 POSTHARVEST DISEASES

INTEGRATED CONTROL OF POSTHARVEST DISEASES

Effective and consistent control of storage diseases depends on integration of the following practices:

- Select disease resistant cultivars where possible.
- Maintain correct crop nutrition by use of leaf and soil analysis.
- Irrigate based on crop requirements and avoid overhead irrigation.
- Apply preharvest treatments to control insects and diseases.
- Harvest the crop at the correct maturity for storage.
- Apply postharvest treatments to disinfest and control diseases and disorders on produce.
- Maintain good sanitation in packing areas and keep dump water free of contamination.
- Store produce under conditions least conducive to growth of pathogens.

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| Vegetable | Disease | Causal Agent | Fungal Class/Type |
|-----------|--------------------|-----------------------------|-------------------|
| Artichoke | Gray mold | Botrytis cinerea | Hyphomycete |
| | Watery soft rot | Sclerotinia sclerotiorum | Discomycete |
| Asparagus | Bacterial soft rot | Erwinia or Pseudomonas spp. | Bacteria |
| | Fusarium rot | $Fusarium { m spp.}$ | Hyphomycete |
| | Phytophthora rot | Phytophthora spp. | Oomycete |
| | Purple spot | $Stemphylium \ { m spp.}$ | Hyphomycete |
| Bulbs | Bacterial soft rot | Erwinia caratovora | Bacterium |
| | Black rot | Aspergillus niger | Hyphomycete |
| | Blue mold rot | Penicillium spp. | Hyphomycete |
| | Fusarium basal rot | $Fusarium\ oxysporum$ | Hyphomycete |
| | Neck rot | Botrytis spp. | Hyphomycete |
| | Purple blotch | Alternaria porri | Hyphomycete |
| | Sclerotium rot | Sclerotium rolfsii | Agonomycete |
| | Smudge | Colletotrichum circinans | Coelomycete |
| Carrot | Bacterial soft rot | $Erwinia 	ext{ spp.}$ | Bacteria |
| | | $Pseudomonas \ { m spp}.$ | |
| | Black rot | A. radicina | Hyphomycete |
| | Cavity spot | Disease complex | Soil fungi |
| | Chalaropsis rot | $Chalara \ { m spp}.$ | Hyphomycetes |
| | Crater rot | R. carotae | Agonomycete |
| | Gray mold rot | B. cinerea | Hyphomycete |
| | Sclerotium rot | S. rolfsii | Agonomycete |
| | Watery soft rot | Sclerotinia spp. | Discomycete |

| Bacteria Hyphomycete Hyphomycete | Hyphomycete Hyphomycete | Coelomycete | Coelomycete | Hyphomycete | Bacterium | Bacterium | Oomycete | Agonomycete | Loculoascomyete | Virus | | Discomycete | Oomycete |
|---|---|-----------------------------------|-------------------|----------------------|--------------------|---------------------------|---------------------------|--------------------|-----------------------------|--------------------------|---------------------|------------------|-------------------|
| Erwinia or Pseudomonas spp. Cephalosporium apii Cercospora apii | Botrytis cinerea Mycocentrospora acerina | Phoma apiicola Selerotinia sun | Septoria apiicola | Alternaria spp. | $E.\ caratovora$ | $Xanthomonas\ campestris$ | $Peronospora\ parasitica$ | Rhizoctonia solani | Mycosphaerella brassicicola | Cauliflower mosaic virus | Turnip mosaic virus | Sclerotinia spp. | $Albugo\ candida$ |
| Bacterial soft rot Brown spot Cercospora spot | Gray mold Licorice rot | Phoma rot Pink rot | Septoria spot | Alternaria leaf spot | Bacterial soft rot | Black rot | Downy mildew | Rhizoctonia rot | Ring spot | Virus diseases | | Watery soft rot | White blister |

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| TABLE 8.34. | IMPORTANT POSTHARVEST DIS | TABLE 8.34. IMPORTANT POSTHARVEST DISEASES OF VEGETABLES (Continued) | (1 |
|--------------------|--|---|--|
| Vegetable | Disease | Causal Agent | Fungal Class/Type |
| Cucurbits | Anthraenose Bacterial soft rot Black rot Botryodiplodia rot Charcoal rot Fusarium rot Leak Rhizopus rot Selerotium rot | Colletotrichum spp. Erwinia spp. Didymella bryoniae Botryodiplodia theobromae Macrophomina phaseolina Fusarium spp. Pythium spp. Rhizopus spp. Sclerotium rolfsii R. solani | Coelomycete Bacterium Loculoascomycete Coelomycete Coelomycete Hyphomycete Oomycete Zygomycete Agonomycete |
| Legumes | Alternaria blight Anthracnose Ascochyta pod spot Bacterial blight Chocolate spot Cottony leak | A. alternata Colletotrichum spp. Ascochyta spp. Pseudomonas spp. Xanthomonas spp. B. cinera Pythium spp. Mycosphaerella blight M. pinodes | Hyphomycete Coelomycete Coelomycetes Bacteria Hyphomycete Oomycete |
| | Rust Sclerotium rot Soil rot White mold | Uromyces spp. S. rolfsti R. solani Sclerotinia spp. | Hemibasidiomycete Agonomycete Agonomycete Discomycete |

| Bacterial rot | Erwinia, Pseudomonas, Xanthomonas spp. | Bacteria |
|--------------------|---|--------------|
| Gray mold rot | B. cinerea | Hyphomycete |
| Rhizoctonia rot | R. solani | Agonomycete |
| Ringspot | Microdochium panattonianum | Hyphomycete |
| Septoria spot | S. lactucae | Coelomycete |
| Stemphylium spot | $Stemphylium\ herbarum$ | Hyphomycete |
| Watery soft rot | Sclerotinia spp. | Discomycete |
| Bacterial soft rot | Erwinia spp. | Bacteria |
| Blight | Phytophthora infestans | Oomycete |
| Charcoal rot | S. bataticola | Agonomycete |
| Common scab | $Streptomyces\ scabies$ | Actinomycete |
| Fusarium rot | Fusarium spp. | Hyphomycete |
| Gangrene | Phoma exigua | Coelomycete |
| Ring rot | Clavibacter michiganensis | Bacterium |
| Sclerotium rot | S. rolfsii | Agonomycete |
| Silver scurf | Helminthosporium solani | Hyphomycete |
| Watery wound rot | $Pythium 	ext{ spp.}$ | Oomycete |

TABLE 8.34. IMPORTANT POSTHARVEST DISEASES OF VEGETABLES (Continued)

| Vegetable | Disease | Causal Agent | Fungal Class/Type |
|--------------------|--|---|--|
| Solanaceous Fruits | Alternaria rot Anthracnose Bacterial canker Bacterial speck Bacterial spot Fusarium rot Gray mold rot Light blight Phoma rot Phomopsis rot Phytophthora rot Pleospora rot Rhizopus rot Selerotium rot Soil rot | A. alternata Colletotrichum spp. C. michiganensis Pseudomonas syringae X. campestris Fusarium spp. B. cinera P. infestans Phoma lycopersici Phytophthora spp. Phytophthora spp. Stemphylium herbarum Rhizopus spp. S. rolfsii R. solani Geotrichum candidum | Hyphomycete Coelomycete Bacterium Bacterium Hyphomycete Oomycete Hyphomycete Coelomycete Typhomycete Coelomycete Apphomycete Apphomycete Apphomycete Apphomycete Hyphomycete Hyphomycete Agonomycete Agonomycete |
| Sweet potato | Watery soft rot Black rot Fusarium rot Rhizopus rot Soil rot | Sclerotinia spp. Ceratocystis fimbriata Fusarium spp. Rhizopus spp. Streptomyces ipomoeae Monilochaetes infuscans | Discomycetes Pyrenomycete Hyphomycetes Zygomycetes Actinomycete |

Adapted from Peter L. Sholberg and William S. Conway, "Postharvest Pathology," in The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks (2004), http://www.ba.ars.usda.gov/hb66/contents.html.

08 VEGETABLE QUALITY

Quality is defined as "any of the features that make something what it is" or "the degree of excellence or superiority." The word quality is used in various ways in reference to fresh fruits and vegetables, such as market quality, edible quality, dessert quality, shipping quality, table quality, nutritional quality, internal quality, and appearance quality.

Quality of fresh vegetables is a combination of characteristics, attributes, and properties that give the vegetables value to humans for food and enjoyment. Producers are concerned that their commodities have good appearance and few visual defects, but for them a useful variety also must score high on yield, disease resistance, ease of harvest, and shipping quality. To receivers and market distributors, appearance quality is most important; they are also keenly interested in firmness and long storage life. Consumers consider good-quality vegetables those that look good, are firm, and offer good flavor and nutritive value. Although consumers buy on the basis of appearance and feel, their satisfaction and repeat purchases depend on good edible quality.

TABLE 8.35. QUALITY ASSURANCE RECORDS FOR VEGETABLES

Field packing

Maturity/ripeness stage and uniformity

Harvest method (hand or mechanical)

Temperature of product (harvest during cool times of the day and keep product shaded)

Uniformity of packs (size, trimming, maturity)

Well-constructed boxes; palletization and unitization

Condition of field boxes or bins (no rough or dirty surfaces)

Cleaning and sanitization of bins and harvest equipment

Packinghouse

Time from harvest to arrival

Shaded receiving area

Uniformity of harvest (size, trimming, maturity)

Washing/hydrocooling operation (sanitization)

Water changed daily and constant sanitizer levels maintained in dump tanks

TABLE 8.35. QUALITY ASSURANCE RECORDS FOR VEGETABLES (Continued)

Decay control chemical usage

Sorting for size, color, quality, etc.

Product that falls on the floor discarded

Culls checks for causes of rejection and for sorting accuracy

Facilities and equipment sanitized regularly

Well-constructed boxes; palletization and unitization

Cooler

Time from harvest to cooler

Time from arrival to start of cooling

Package design (ventilation)

Speed of cooling and final temperature

Temperature of product after cooling

Temperature of holding room

Time from cooling to loading

Loading Trailer

First-in, first-out truck loading

Temperature of product

Boxes palletized and unitized

Truck condition (clean, undamaged, precooled)

Loading pattern; palletization and unitization

Duration of transport

Temperature during transport (thermostat setting and use of recorders)

Arrival at Distribution Center

Transit time

Temperature of product

Product condition and uniformity

Uniformity of packs (size, trimming, maturity)

Ripeness stage, firmness

Decay incidence/type

Refrigeration maintained during cooling

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TABLE 8.36. QUALITY COMPONENTS OF FRESH VEGETABLES

| Main Factors | Components |
|--------------------------|--|
| Appearance (visual) | Size: dimensions, weight, volume Shape and form: diameter/depth ratio, |
| | compactness, uniformity |
| | Color: uniformity, intensity |
| | Gloss: nature of surface wax |
| | Defects, external and internal: morphological, |
| | physical and mechanical, physiological, pathological, entomological |
| Texture (feel) | Firmness, hardness, softness |
| | Crispness |
| | Succulence, juiciness |
| | Mealiness, grittiness |
| | Toughness, fibrousness |
| Flavor (taste and smell) | Sweetness |
| | Sourness (acidity) |
| | Astringency |
| | Bitterness |
| | Aroma (volatile compounds) |
| | Off-flavors and off-odors |
| Nutritional value | Carbohydrates (including dietary fiber) |
| | Proteins |
| | Lipids |
| | Vitamins |
| | Essential elements |
| Safety | Naturally occurring toxicants |
| | Contaminants (chemical residues, heavy metals) |
| | Mycotoxins |
| | Microbial contamination |

Adapted from A. A. Kader (ed.), *Postharvest Technology of Horticultural Crops*, 3rd ed. (University of California, Division of Agriculture and Natural Resources Publication 3311, 2002).

09 U.S. STANDARDS FOR GRADES OF VEGETABLES

Grade standards issued by the U.S. Department of Agriculture (USDA) are currently in effect for most vegetables for fresh market and for processing. Some standards have been unchanged since they became effective, whereas others have been revised quite recently.

For the U.S. Standards for Grades of Fresh and Processing Vegetables, go to:

http://www/ams.usda.gov/standards/stanfrfv.htm

TABLE 8.37. QUALITY FACTORS FOR FRESH VEGETABLES IN THE U.S. STANDARDS FOR GRADES

| Vegetable | Date Issued | Quality Factors |
|-------------------------|----------------|---|
| Anise, sweet | 1973 | Firmness, tenderness, trimming, blanching, and freedom from decay and damage caused by growth cracks, pithy branches, wilting, freezing, seedstems, insects, and mechanical means |
| Artichoke | 1969 | Stem length, shape, overmaturity, uniformity of size, compactness, and freedom from decay and defects |
| Asparagus | 1966 | Freshness (turgidity), trimming, straightness, freedom from damage and decay, diameter of stalks, percent green color |
| Bean, lima | 1938 | Uniformity, maturity, freshness, shape, and freedom from damage (defect) and decay |
| Bean, snap | 1936 | Uniformity, size, maturity, firmness, and freedom from defect and decay |
| Beet, bunched or topped | 1955 | Root shape, trimming of rootlets, firmness (turgidity), smoothness, cleanness, minimum size (diameter), and freedom from defect |
| Beet, greens | 1959 | Freshness, cleanness, tenderness, and freedom from decay, other kinds of leaves, discoloration, insects, mechanical injury, and freezing injury |
| Broccoli | 1943 | Color, maturity, stalk diameter and length, compactness, base cut, and freedom from defects and decay |
| Brussels sprouts | 1954 | Color, maturity (firmness), no seedstems, size (diameter and length), and freedom from defect and decay |
| Cabbage | 1945 | Uniformity, solidity (maturity or firmness), no seedstems, trimming, color, and freedom from defect and decay |
| Cantaloupe | 1968 | Soluble solids (>9 percent), uniformity of size, shape, ground color and netting; maturity and turgidity; and freedom from wet slip, sunscald, and other defects |

TABLE 8.37. QUALITY FACTORS FOR FRESH VEGETABLES IN THE U.S. STANDARDS FOR GRADES (Continued)

| Vegetable | Date Issued | Quality Factors |
|----------------------|----------------|---|
| Carrot, bunched | 1954 | Shape, color, cleanness, smoothness, freedom from defects, freshness, length of |
| Carrot, topped | 1965 | Ups, and root diameter Uniformity, turgidity, color, shape, size, cleanness, smoothness, and freedom from defeat (grouth grapes nithings woodings internal discolaration) |
| Carrots with short | 1954 | Roots; firmness, color, smoothness, and freedom from defect (sunburn, pithiness, |
| trimmed tops | | woodiness, internal discoloration, and insect and mechanical injuries) and decay; leaves: (cut to <4 inches) freedom from yellowing or other discoloration, |
| | | disease, insects, and seedstems |
| Cauliflower | 1968 | Curd cleanness, compactness, white color, size (diameter), freshness and trimming of jacket leaves, and freedom from defect and decay |
| Celery | 1959 | Stalk form, compactness, color, trimming, length of stalk and midribs, width and thickness of midribs, no seedstems, and freedom from defect and decay |
| Collard greens or | 1953 | Freshness, tenderness, cleanness, and freedom from seedstems, discoloration, |
| broccoli greens | | freezing injury, insects, and diseases |
| Corn, sweet | 1992 | Uniformity of color and size, freshness, milky kernels, cob length, freedom from insect injury, discoloration, and other defects, coverage with fresh husks |
| Cucumber | 1958 | Color, shape, turgidity, maturity, size (diameter and length), and freedom from defect and decay |
| Cucumber, greenhouse | 1985 | Freshness, shape, firmness, color, size (11 in. or longer), and freedom from decay, cuts, bruises, scars, insect iniury, and other defects |
| Dandelion greens | 1955 | Freshness, cleanness, tenderness, and freedom from damage caused by seedstems, discoloration, freezing, diseases, insects, and mechanical injury |

TABLE 8.37. QUALITY FACTORS FOR FRESH VEGETABLES IN THE U.S. STANDARDS FOR GRADES (Continued)

| Vegetable | Date Issued | Quality Factors |
|----------------------------------|----------------|--|
| Mustard greens and turnip greens | 1953 | Freshness, tenderness, cleanness, and freedom from damage caused by seedstems, discoloration, freezing, disease, insects, or mechanical means; roots (if attached): firmness and freedom from damage |
| Okra Onion, drv | 1928 | Freshness, uniformity of shape and color, and freedom from defect and decay |
| Creole | 1943 | Maturity, firmness, shape, size (diameter), and freedom from decay, wet sunscald, doubles, bottlenecks, sprouting, and other defects |
| Bermuda-Granex- Grano | 1995 | Maturity, firmness, shape, size (diameter) and freedom from decay, wet sunscald, doubles, bottlenecks, seedstems, sprouting and other defects |
| Other varieties | 1995 | Maturity firmness, shape, size (diameter), and freedom from decay, wet sunscald, doubles, bottlenecks, sprouts and other defects. |
| Onion, green | 1947 | Turgidity, color, form, cleanness, bulb trimming, no seedstems, and freedom from defect and decay |
| Onion sets | 1940 | Maturity, firmness, size, and freedom from decay and damage caused by tops, sprouting freezing mold moisture dirt. disease insects, or mechanical means |
| Parsley Parsnip | 1930 1945 | Freshness, green color, and freedom from defects, seedstems, and decay Turgidity, trimming, cleanness, smoothness, shape, freedom from defects and decay, and size (diameter) |

| Pea, fresh | 1942 | Maturity, size, shape, freshness, and freedom from defects and decay |
|------------------|------|--|
| Pepper, sweet | 1989 | Maturity, color, shape, size, firmness, and freedom from defects (sunburn, sunscald, freezing injury, hail, scars, insects, mechanical damage) and decay |
| Potato | 1991 | Uniformity, maturity, firmness, cleanness, shape, size, and freedom from sprouts, scab, growth cracks, hollowheart, blackheart, greening, and other defects |
| Radish | 1968 | Tenderness, cleanness, smoothness, shape, size, and freedom from pithiness and other defects; tops of bunched radishes fresh and free from damage |
| Rhubarb | 1966 | Color, freshness, straightness, trimming, cleanness, stalk diameter and length, and freedom from defect |
| Shallot, bunched | 1946 | Firmness, form, tenderness, trimming, cleanness, and freedom from decay and damage caused by seedstems, disease, insects, mechanical and other means; tops: freshness, green color, and no mechanical damage |
| Southern pea | 1956 | Maturity, pod shape, and freedom from discoloration and other defects |
| Spinach bunches | 1987 | Freshness, cleanness, trimming, and freedom from decay and damage caused by coarse stalks or seedstems, discoloration, insects, or mechanical means |
| Spinach leaves | 1946 | Color, turgidity, cleanness, trimming, and freedom from seedstems, coarse stalks, and other defects |
| Squash, summer | 1984 | Immaturity, tenderness, shape, firmness, and freedom from decay, cuts, bruises, scars, and other defects |

QUALITY FACTORS FOR FRESH VEGETABLES IN THE U.S. STANDARDS FOR GRADES (Continued) **TABLE 8.37.**

| Date getable Issued | inter, and 1983 Maturity, firmness, freedom from discoloration, cracking, dry rot, insect damage, and other defects; uniformity of size 1965 Maturity (>½ or >¾ of surface showing red or pink color, depending on grade), firmness, attached calyx, size, and freedom from defect and decay | 1963 Firmness, smoothness, cleanness, shape, size, and freedom from mechanical damage, growth cracks, internal breakdown, insect damage, other defects, and decay | 1991 Maturity and ripeness (color chart), firmness, shape, size, and freedom from defect (puffiness, freezing injury, sunscald, scars, catfaces, growth cracks, insect injury, and other defects) and decay | 1966 M | d rutabaga 1955 Uniformity of root color, size, and shape, trimming, freshness, and freedom from defects (cuts, growth cracks, pithiness, woodiness, water core, dry rot) | 2006 M |
|------------------------|---|---|---|--------------------|---|------------|
| Vegetable | Squash, winter, and pumpkin Strawberry | Sweet potato | Tomato | Tomato, greenhouse | Turnip and rutabaga | Watermelon |

Adapted from A. A. Kader (ed.), Postharvest Technology of Horticultural Crops, 3rd ed. (University of California, Division of Agriculture and Natural Resources Publication 3311, 2002).

QUALITY FACTORS FOR PROCESSING VEGETABLES IN THE U.S. STANDARDS FOR GRADES **TABLE 8.38.**

| Vegetable | Date Issued | Quality Factors |
|--------------------|-------------|---|
| Asparagus, green | 1972 | Freshness, shape, green color, size (spear length), and freedom from defect (freezing damage, dirt, disease, insect injury, and mechanical injuries) and |
| Bean, shelled lima | 1953 | decay Tenderness green color, and freedom from decay and from injury caused by discoloration, shriveling, sunscald, freezing, heating, disease, insects, or other |
| Bean, snap | 1985 | means Freshness, tenderness, shape, size, and freedom from decay and from damage caused by scars, rust, disease, insects, bruises, punctures, broken ends, or other |
| Beet | 1945 | Firmness, tenderness, shape, size, and freedom from soft rot, cull material, growth cracks, internal discoloration, white zoning, rodent damage, disease, incores, and machanical injury. |
| Broccoli | 1959 | Insects, and incommentary, and freedom from Freshness, trimming, and freedom from decay and damage caused by discoloration, freezing, pithiness, scars, dirt, or machanical manner. |
| Cabbage | 1944 | Firmness, trimming, and freedom from soft rot, seedstems, and from damage caused by bursting, discoloration, freezing, disease, birds, insects, or mechanical or other means |
| Carrot | 1984 | Firmness, color, shape, size (root length), smoothness, not woody, and freedom from soft rot, cull material, and from damage caused by growth cracks, sunburn, green core, pithy core, water core, internal discoloration, disease, or mechanical means |

TABLE 8.38. QUALITY FACTORS FOR PROCESSING VEGETABLES IN THE U.S. STANDARDS FOR GRADES (Continued)

| Vegetable | Date Issued | Quality Factors |
|--|-------------|--|
| Cauliflower | 1959 | Freshness, compactness, color, and freedom from jacket leaves, stalks, and other cull material, decay, and damage caused by discoloration, bruising, fuzziness, enlarged bracts, dirt, freezing, hail, or mechanical means |
| Corn, sweet | 1962 | Maturity, freshness, and freedom from damage by freezing, insects, birds, disease, cross-pollination, or fermentation |
| Cucumber, pickling | 1936 | Color, shape, freshness, firmness, maturity, and freedom from decay and from damage caused by dirt, freezing, sunburn, disease, insects, or mechanical or other means |
| Mushroom | 1964 | Freshness, firmness, shape, and freedom from decay, disease spots, and insects, and from damage caused by insects, bruising, discoloration, or feathering |
| Okra | 1965 | Freshness, tenderness, color, shape, and freedom from decay and insects, and from damage caused by scars, bruises, cuts, punctures, discoloration, dirt or other means |
| Onion | 1944 | Maturity, firmness, and freedom from decay, sprouts, bottlenecks, scallions, seedstems, sunscald, roots, insects, and mechanical injury |
| Pea, fresh shelled for canning/ freezing | 1946 | Tenderness, succulence, color, and freedom from decay, scald, rust, shriveling, heating, disease, and insects |
| Pepper, sweet | 1948 | Firmness, color, shape, and freedom from decay, insects, and damage by any means that results in 5–20% trimming (by weight) depending on grade |
| Potato | 1983 | Shape, smoothness, freedom from decay and defect (freezing injury, blackheart, sprouts), size, specific gravity, glucose content, and fry color |

| Potato for chipping | 1978 | Firmness, cleanness, shape, freedom from defect (freezing, blackheart, decay, insect injury, and mechanical injury), size; optional tests for specific gravity and fry color included |
|-------------------------------------|------|---|
| Southern pea | 1965 | Pods: maturity, freshness, and freedom from decay; seeds: freedom from scars, insects, decay, discoloration, splits, cracked skin, and other defects |
| Spinach | 1956 | Freshness, freedom from decay, grass weeds, and other foreign material, and freedom from damage caused by seedstems, discoloration, coarse stalks, insects, dirt, or mechanical means |
| Sweet potato for canning/freezing | 1959 | Firmness, shape, color, size, and freedom from decay and defect (freezing injury, scald, cork, internal discoloration, bruises, cuts, growths cracks, pithiness, stringiness, and insect injury) |
| Sweet potato for dicing/pulping | 1951 | Firmness, shape size, and freedom from decay and defect (scald, freezing injury, cork, internal discoloration, pithiness, growth cracks, insect damage, and stringiness) |
| Tomato | 1983 | Firmness, ripeness (color as determined by a photoelectric instrument), and freedom from insect damage, freezing, mechanical damage, decay, growth cracks, sunscald, grav wall, and blossom-end rot |
| Tomato, green | 1950 | Firmness, color (green), and freedom from decay and defect (growth cracks, scars, catfaces, sunscald, disease, insects, or mechanical damage) |
| Tomato, Italian type for canning | 1957 | Firmness, color uniformity, and freedom from decay and defect (growth cracks, sunscald, freezing, disease, insects, or mechanical injury) |

Adapted from A. A. Kader (ed.), Postharvest Technology of Horticultural Crops, 3rd ed. (University of California, Division of Agriculture and Natural Resources Publication 3311, 2002).

INTERNATIONAL STANDARDS

International standards for vegetables published by the Organization for Economic Cooperation and Development (OECD) are available from the OECD Bookshop at http://www.oecdbookshop.org in the series International Standardization of Fruit and Vegetables.

Ontario, Canada, Grading and Packing Manuals are available at:

http://www.gov.on.ca/omafra/english/food/inspection/fruitveg/intro.htm

10 MINIMALLY PROCESSED VEGETABLES

Helpful website: http://www.fresh-cuts.org

TABLE 8.39. BASIC REQUIREMENTS FOR PREPARATION OF MINIMALLY PROCESSED VEGETABLES

High-quality raw material Variety selection

Production practices

Harvest and storage conditions

Strict hygiene and good manufacturing practices

Use of Hazard Analysis Critical Control Points principles

Sanitation of processing line, product, and workers

Low temperatures during processing

Careful cleaning and/or washing before and after peeling

Good-quality water (sensory, microbiological, pH)

Use of mild processing aids in wash water for disinfection or prevention of browning and texture loss

Chlorine, ozone, and other disinfectants

Antioxidant chemicals such as ascorbic acid, citric acid, etc.

Calcium salts to reduce textural changes

Minimal damage during peeling, cutting, slicing, and shredding operations

Sharp knives and blades on cutters

Elimination of defective and damaged pieces

Gentle draining, spin- or air-drying to remove excess moisture

Correct packing materials and packaging methods

Selection of plastic films to ensure adequate O2 levels to avoid fermentation

Correct temperature during distribution and handling

All minimally processed products kept at 32-41°F

Adapted from A. A. Kader (ed.), *Postharvest Technology of Horticultural Crops*, 3rd ed. (University of California, Division of Agriculture and Natural Resources Publication 3311. 2002).

TABLE 8.40. ADVANTAGES, DISADVANTAGES, AND REQUIREMENTS OF FRESH-CUT VEGETABLE PRODUCTS PREPARED AT DIFFERENT LOCATIONS

| Location of Processing | Characteristics and Requirements |
|------------------------|--|
| Source of production | Raw product processed fresh when it is of the highest quality. |
| | Processed product requires a minimum of 14 days postprocessing shelf life. |
| | Good temperature management critical. |
| | Economy of scale. |
| | Avoid long-distance transport of unusable product. |
| | Vacuum- and gas-flushing common; differentially permeable films. |
| Regional | Raw product processed when of good quality, |
| | typically 3–7 days after harvest. |
| | Reduced need to maximize shelf life; about 7 days postprocessing life required. |
| | Good temperature management vital. |
| | Several deliveries weekly to end-users. |
| | Can better respond to short-term demands. |
| | Vacuum- and gas-flushing common; differentially permeable films. |
| Local | Raw product quality may vary greatly because |
| | processed 7–14 days after harvest. |
| | Relatively short postprocessing life required or expected. |
| | Good temperature management required but is often deficient. |
| | Small quantities processed and delivered. |
| | More labor intensive; discard large amounts of unusable product. |
| | Simpler and less costly packaging; less use of vacuum- or gas-flushing techniques. |

Adapted from A. A. Kader (ed.), *Postharvest Technology of Horticultural Crops*, 3rd ed. (University of California, Division of Agriculture and Natural Resources publication 3311, 2002).

TABLE 8.41. PHYSIOLOGY AND STORAGE CHARACTERISTICS OF FRESH-CUT VEGETABLES (ALL PRODUCTS SHOULD BE STORED AT 32–41°F)

| Beneficial Atmosphere | %0 ₂ %CO ₂ | 10-20 10-15 | 3-12 | 5 | | 5-15 | -5 10 | 0 <5 | 1 | 1 | 5-10 | 10 | 5 | <0.5-3 10-15 | 5-10 |
|--------------------------|---|---------------------|-------------|---------------------|----------------------|----------|---------------------------------------|--------------------------|--------------------------|----------|------------------------------|------------------------|---------------|-----------------------|-----------------------|
| At E |)% | 10-5 | 2-5 | 5 | 3-10 | 3 - 7 | 0.5 - 5 | 5-10 | ı | I | က | က | 5 | \ \ 0. | 1 - 3 |
| | Common Quality Defects (other than microbial growth) | Browning, softening | Browning | Leakage; color loss | Yellowing, off-odors | Browning | Surface drying (white blush), leakage | Discoloration; off odors | Browning, surface drying | Leakage | Sprout growth, discoloration | Browning; texture loss | Discoloration | Browning of cut edges | Browning of cut edges |
| Resniration Rate in | Air at 41° Fresh-cut Product (mL $\mathrm{CO_2 \cdot kg^{-1} \cdot h^{-1}})$ | 40 | 15–18 | 5 | 20-35 | 13-20 | 7-10; 12-15 | I | 2-3 | 5 | 20 | 5-10 | 25 | 6; 10 | 10-13 |
| | Fresh-cut Product | Trimmed spears | Cut | Cubed | Florets | Shredded | Sticks, shredded | Florets | Sticks | Sliced | Peeled clove | Sticks | Sliced | Chopped, shredded | Chopped |
| | Vegetable | Asparagus tips | Beans, snap | Beet | Broccoli | Cabbage | Carrot | Cauliflower | Celery | Cucumber | Garlic | Jicama | Leek | Lettuce, iceberg | Lettuce, other |

TABLE 8.41. PHYSIOLOGY AND STORAGE CHARACTERISTICS OF FRESH-CUT VEGETABLES (ALL PRODUCTS SHOULD BE STORED AT 32–41°F) (Continued)

| | | Dogwinsting Doto in | | Bene Atmos | Beneficial Atmosphere |
|----------------|-------------------|--|--|---------------|--------------------------|
| Vegetable | Fresh-cut Product | Air at 41°F Air at 41°F (mL $\rm CO_2 \cdot kg^{-1} \cdot h^{-1})$ | Common Quality Defects (other than microbial growth) | $\%0_2$ | %CO ₂ |
| | | | | | |
| Cantaloupe | Cubed | 5-8 | Leakage; softening; glassiness (translucency) | 3–5 | 5-15 |
| Honeydew | Cubed | 2-4 | Leakage; softening; glassiness (translucency) | 2-3 | 5-15 |
| Watermelon | Cubed | 2-4 | Leakage; softening | 3–5 | 5-15 |
| Onion, bulb | Sliced, diced | 8-12 | Texture, juice loss, discoloration | 2-5 | 10-15 |
| Onion, green | Chopped | 25-30 | Discoloration, growth; leakage | I | l |
| | Sliced, diced | 3; 6 | Texture loss, browning | က | 5-10 |
| | Sticks, peeled | 4-8 | Browning, drying | 1–3 | 6-9 |
| Rutabaga | Cubed | 10 | Discoloration, drying | 5 | 20 |
| Spinach | Cleaned, cut | 6-12 | Off-odors; rapid deterioration of small | 1–3 | 8-10 |
| | | | pieces | | |
| Squash, summer | Cubed, sliced | 12-24 | Browning; leakage | 1 | I |
| Strawberry | Sliced; topped | 12; 6 | Loss of texture, juice, color | 1-2 | 5-10 |
| | Sliced | 3 | Leakage | က | ಣ |

Adapted from A. A. Kader (ed.), Postharvest Technology of Horticultural Crops, 3rd ed. (University of California, Division of Agriculture and Natural Resources Publication 3311, 2002).

11 CONTAINERS FOR VEGETABLES

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES

| Vegetable | $\operatorname{Container}^1$ | Approximate Net Weight (lb) ^{2, 3} |
|----------------|---------------------------------------|---|
| Artichoke | Carton by count or loose pack | 23 |
| Asparagus | Pyramid cartons or crates | 30 |
| 1 0 | Cartons or crates, bunched | 28 |
| | Lugs or cartons, loose | 25 |
| | Cartons, 16 1½-lb bunches | 24-25 |
| | Lugs or cartons, loose | 21 |
| | Pyramid carton or crate, ½ | 20 |
| | Carton, bunched | 20 |
| | Pyramid carton or crate, ½ | 15-17 |
| | Carton, bunched | 14 |
| | Carton, loose | 15 |
| | Carton, ½ | 12 |
| | Carton or crate, ½ | 12-13 |
| | Carton or crate | 11 |
| Bean | Wirebound crate or hamper, bushel | 26 - 31 |
| | Carton or crate | 25 - 30 |
| Green | Carton | 20-22 |
| | Presnipped bags, retail | 12 oz^3 |
| | Presnipped bags, foodservice | 10 |
| Yellow | Wirebound crate or hamper | 30 |
| | Carton | 25 - 30 |
| | Carton | 15 |
| Beet, Bunched | Wirebound crate or carton, 12 bunches | 45 |
| | Carton or crate, 24 bunches | 38 |
| Topped | Mesh sack | 50 |
| r r | Sack | 25 |
| | Carton or crate, 12 bunches | 20 |
| Belgian endive | Carton | 10 |
| Bitter melon | Crate | 40 |
| | Carton or crate | 30 |

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES (Continued)

| Vegetable | ${ m Container}^1$ | Approximate Net Weight (lb) ^{2, 3} |
|------------------|---------------------------------------|---|
| | O. A. | 90 |
| | Carton Carton | 20 10 |
| | Carton | 10 5 |
| Boniato | Carton or sack | 50 |
| Domaw | Carton | 10 |
| Brussels sprouts | Cartons, loose | 25 |
| Diassels spioats | Flats or cartons, 16 12-oz cello bags | 10 |
| | 8 1-lb clamshells | 8 |
| | 24 1-lb Vexar bags | 25 |
| Cabbage | Bulk bin | 2,000 |
| | Bulk bin | 1,000 |
| | Flat crate | 50-60 |
| | Carton or mesh sack | 50 |
| | Crate, 1¾ bushel | 50 |
| | Carton | 45 |
| | Carton (savoy) | 20 |
| Calabaza | Bin | 800 |
| | Carton or sack | 50 |
| Carrot | Table carton | 50 |
| | 48 1-lb film bags | 48 |
| | Table poly bags | 25 |
| | 24 2-lb poly bags | 48 |
| | 12 2-lb poly bags | 24 |
| | 5 10-lb poly bags | 50 |
| | 16 3-lb poly bags | 48 |
| | 10 5-lb poly bags | 50 |
| Bunched | Carton | 26 |
| Baby, peeled | Carton 20 1-lb bags | 20 |
| | 24 1-lb bags | 24 |
| | 40 1-lb bags | 40 |
| | 10 2-lb bags | 20 |
| | 12 2-lb bags | 24 |
| | 20 2-lb bags | 40 |
| | 4 5-lb bags | 20 |

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES (Continued)

| 77 | | Approximate Net Weight |
|-------------|---|---------------------------|
| Vegetable | ${ m Container^1}$ | $(lb)^{2, 3}$ |
| | | |
| | 8 5-lb bags | 40 |
| | 73 3-oz bags | 14 |
| Foodservice | Poly jumbo | 25 |
| | Poly jumbo | 50 |
| Cauliflower | Long Island wirebound crate | 60 |
| | Catskill carton | 50 |
| | Carton, 12- and 16-count film- | 25 – 30 |
| a | wrapped trimmed heads | |
| Celeriac | Crate, 1½ bushel | 35 |
| | Crate | 20 |
| | Carton, 12 count | |
| Celery | Carton or crate | 50-60 |
| Hearts | Carton | 28 |
| | Carton | 18 |
| Chayote | Crate | 50 |
| | Crate | 40 |
| | Carton | 30 |
| | 1-layer flat, 24 count | |
| | Carton | 20 |
| Corn | Carton or crate | 50 |
| | Carton, crate, or sack | 42 |
| | Wirebound crate | 42 |
| | Sack | 37 |
| | Carton, 48 count | |
| | 12 	imes 4 packaged tray pack | |
| | 12 	imes 3 packaged tray pack | |
| Cucumber | Carton or crate, 1½ bushel | 55 |
| | Carton, 3.56 decaliter | 55 |
| | Carton, 48 count | 30 |
| | Carton or crate, ⁵ / ₈ bushel | 28 |
| | Carton, 36–42 count | 28 |
| | Carton, 36–42 count (CA) | 24 |
| | Carton, 24 count | 22 |
| Greenhouse | Carton, film wrapped | 16 |
| | Carton or flat, film wrapped | 12 |

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES (Continued)

| Vegetable | ${ m Container}^1$ | Approximate Net Weight (lb) ^{2, 3} |
|-----------------|---|---|
| D. 1 | 0.1 | F0 |
| Daikon | Carton or crate | 50 |
| | Carton or crate | 45 |
| | Carton or crate, 1½ bushel | 40 |
| | Box, crate, or lug | 20 |
| | Carton | 10 |
| D 1 . | Carton | 5 |
| Eggplant | Carton, crate, or basket; bushel or $1\frac{1}{9}$ bushel | 33 |
| | Carton, 3.56 decaliter | 33 |
| | Carton, crate, or lug | 25 |
| | L.A. lug or carton, 18–24 count | |
| | Lug, $\frac{1}{2}$ and $\frac{5}{8}$ bushel | 17 |
| Chinese | Lug | 26 |
| | Carton | 25 |
| | Carton or crate, ½ and ½ bushel | 15 |
| Italian | Lug | 26 |
| | Carton or crate, ½ and 5/8 bushel | 15 |
| Japanese | Carton or crate, ½ and 5/8 bushel | 15 |
| Endive/Escarole | Carton, 24 count | 34 |
| | Crate, 3-wire celery, 24 count | 30-40 |
| | Crate, 15/8 bushel | Various |
| | Crate, % bushel | Various |
| Garlic | Carton | 5 |
| | Carton | 10 |
| | Carton | 15 |
| | Carton | 22 |
| | Carton | 30 |
| | Bag | 3 |
| | Bag | $3 \ 16 - oz^3$ |
| | Cello bag or tray; 2, 3, 4 count | |
| Ginger | Carton | 30 |
| • | Carton | 20 |
| | Carton or film bag | 5 |

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES (Continued)

| Vegetable | ${ m Container}^1$ | Approximate Net Weight (lb) ^{2, 3} |
|------------------------------------|--|---|
| Conservation (collection) | Create 12/ 13/ burshel | 30–35 |
| Greens (collards and dandelion) | Crate, 1½, 1½ bushel Basket, crate or carton; bushel | 20–25 |
| and dandenon) | Crate or carton, 12–24 bunch count | 20-25 |
| Haricot vert | Tray | 11 |
| | Tray | 10 |
| | Tray | 5 |
| Jerusalem artichoke | Carton | 25 |
| | Carton | 20 |
| | Carton | 10 |
| | Carton | 5 |
| Jicama | Crate, 1½ bushel | 45 |
| | Wirebound crate | 40 |
| | Carton or crate | 20 |
| | Carton | 10 |
| Leek | Carton, 12 bunches | 30 |
| | Carton, 24 bunches | 24 - 30 |
| | Carton or crate, ⁴ / ₅ bushel | 20 |
| | Carton, 10 1-lb film bag | 10 |
| Lettuce, iceberg | Carton; 18, 24, 30 count | 50 |
| | Carton | 30 |
| | Carton; 15, 16 count | 20 |
| Boston | Crate, 1½ bushel | 22 |
| | Carton or crate, 24 count | 20 |
| | Flat, carton, or crate | 10 |
| | Basket or carton, 12 q | 5 |
| Bibb | Flat, carton, or crate | 10 |
| | Basket or carton, 12 q | 5 |
| | Basket, greenhouse | 5 |
| Leaf | Carton or crate, 24 count | 25 |
| | Crate, ½ bushel | 20 |
| | Crate, 1 ² / ₃ bushel | 14 |
| | Basket or carton, 24 q | 10 |
| | Carton | 3 |

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES (Continued)

| Vegetable | ${ m Container}^1$ | Approximate Net Weight (lb) ^{2, 3} |
|-------------------|---|---|
| | Carton | 2 |
| Processed iceberg | Carton, chopped | 20 |
| J | Carton, chopped or cleaned/cored | 30 |
| | Bins | 1,000 |
| Romaine | Carton; ² / ₃ , 24 count (West) | 40 |
| | Carton | 40 |
| | Carton, 1.3 bushel | 28 |
| | Carton or crate, 1½ bushel | 22 |
| | Carton, 24 count (East) | 22 |
| | Carton, 12 count | 18 |
| Lo Bok | Crate | 45 |
| | Crate | 40 |
| | Carton, crate, or lug | 25 |
| Long bean | Carton | 40 |
| | Crate | 30 |
| | Carton | 10 |
| | Carton | 5 |
| Melon | | |
| Cantaloupe | Bin | 1,000 |
| | Jumbo crate | 80 |
| | $1\frac{3}{4}$ bushel cartons or crates | 60 |
| | Carton or crate, ½ | 54 |
| | Carton or crate, ½ | 40 |
| | Carton or crate, 1½ bushel | 40 |
| | Bushel basket | 40 |
| | Single-layer pack | 18-21 |
| Honeydew | Flat crate | 35 |
| | Carton, ² / ₃ , various count | 30 |
| | Carton | 30 |
| Mixed | Flat crate | 35 |
| | Carton, various count | 30 |
| Mushroom | Carton, 12 1-lb trays | 12 |
| | Carton | 10 |
| | Carton, 18 8-oz or 8 1-lb trays | 8 |
| | Carton, 12 8-oz trays | 6 |

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES (Continued)

| Vegetable | ${ m Container^1}$ | Approximate Net Weight (lb) ^{2, 3} |
|-----------|-----------------------------------|---|
| | | |
| | Carton | 5 |
| | Basket, 4 q | 3 |
| Napa | WGA crate | 70 |
| | Crate, celery | 50 |
| | Carton | 50 |
| | Crate, 1.3 bushel | 45 |
| | Carton | 45 |
| | Carton or crate, 1½ bushel | 40 |
| | Carton | 30 |
| Okra | Basket, crate, hamper; bushel | 30 |
| | Hamper, ¾ bushel | 23 |
| | Crate or flat, 5/9 bushel | 18 |
| | Basket, crate or lug | 15 |
| Onion | | |
| Bulb | Carton, crate, sack | 50 |
| | Master container, 10 5-lb bags | 50 |
| | Master container, 16 3-lb bags | 48 |
| | Master container, 24 2-lb sacks | 48 |
| | Master container, 15 3-lb sacks | 45 |
| | Master container, 20 2-lb sacks | 40 |
| | Carton | 40 |
| | Master container, 12 3-lb sacks | 36 |
| | Master container, 16 2-lb sacks | 32 |
| | Sack, reds, boilers | 25 |
| | Carton or bag | 25 |
| | Master container, 12 2-lb sacks | 24 |
| | Carton, sack, or bag | 10 |
| | Bag or carton | 5 |
| Green | Carton, bunched bulb-type | 28 |
| | Carton or crate, bunched 24 count | 20 |
| | Carton, bunched 48 count | 13 |
| | Carton, bunched 36 count | 11 |
| Pak choi | WGA Crate | 70 |
| | Crate | 60 |

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES (Continued)

| Vegetable | ${ m Container}^1$ | Approximate Net Weight (lb) ^{2, 3} |
|-------------------|---|---|
| | Carton or crate | 50 |
| | Carton or crate | 40 |
| | Carton or crate | 35 |
| | Carton or crate Carton or crate | 30 |
| Parsley | Carton or crate Carton or wirebound crate, 60 count | 30 |
| | Carton or wirebound crate, 30 count | |
| | Carton or crate, 1½ bushel, bunched | 21 |
| | Carton, crate, or basket, bunched | 11 |
| Parsnip | Carton or crate, ½ bushel | 25 |
| | Film sack | 20 |
| | Carton, 12 1-lb bags | 12 |
| Pea | | |
| Green | Basket, crate, or hamper; 1 bushel | 30 |
| | Crate, 1½ bushel | 30 |
| Edible pod | Carton | 10 |
| Southern | Hamper, 1 bushel | 25 |
| Pepino | Carton, 1 layer | 10 |
| | Carton | 8 |
| Pepper | | |
| Bell | Carton, 1 ¹ / ₉ bushel | 35 |
| | Carton or crate (Mexico) | 30 |
| | Carton or crate, bushel, and 1 ¹ / ₉ bushel | 28 |
| | Carton, 3.56 decaliter | 28 |
| | Carton | 25 |
| | Carton, ½ bushel | 14-15 |
| | Flat carton (Netherlands) | 11 |
| Chiles: jalapeno, | Crate or carton, ½ bushel | |
| yellow wax, | Crate or carton, 5/8 bushel | |
| others | Bin | 500 |

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES (Continued)

| Vegetable | ${ m Container}^1$ | Approximate Net Weight (lb) ^{2, 3} |
|---------------------|---------------------------------|---|
| | | |
| | Crate or carton 1½ bushel | |
| | Cases, bulk | 10 |
| Potato | Sack | 100 |
| | Carton or sack | 50 |
| | Baled, 5 10-lb bags | 50 |
| | Baled, 10 5-lb bags | 50 |
| | Carton, 60–100 count | |
| Prickly pear | Carton | 18 |
| • • | Carton, 35 count | 10 |
| Pumpkin | Bin | 1,000 |
| • | Carton, crate, or sack | 50 |
| | Carton or crate, ½ bushel | 25 |
| Radicchio Radish | Carton or lug | 7 |
| Topped | Sack or bag, loose | 40 |
| 11 | Bag | 25 |
| | Bag, resealable or conventional | 14 |
| | Basket or carton | 12 |
| | Bag, 30 6-oz or 24 8-oz | 12 |
| | Bag, 4 5-lb | 20 |
| Bunched | Carton or crate, 48 count | 35 |
| | Carton or lug, 4/5 bushel | 30 |
| | Carton, 24 count | 25 |
| | Carton or crate, 24 count | 20 |
| | Carton or crate, 24 count | 15 |
| Rhubarb | Carton or lug | 20 |
| | Carton | 15 |
| Rutabaga | Carton or bag, 1 bushel | 50 |
| | Carton or bag, ½ bushel | 25 |
| Salad mix | Carton, 4 5-lb bags | 20 |
| | Carton, 2 10-lb bags | 20 |
| | Carton, 3 24 count (retail) | |
| | Carton, mesclun | 3 |

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES (Continued)

| Vegetable | ${ m Container}^1$ | Approximate Net Weight (lb) ^{2, 3} |
|-----------|------------------------------------|---|
| | | |
| Salsify | Carton | 22 |
| · | Carton | 10 |
| | Bag | 4 |
| Spinach | Carton or crate, 1½ bushel | 32 |
| • | Container, bushel | 25 |
| | Carton, 24-bunch count | 20 |
| | Carton, 12-bunch count | 20 |
| | Bag, 12 10-lb | 120 |
| | Bag, 24-q | 10 |
| | Carton, 12 10-oz bags | 8 |
| Sprouts | , 3 | |
| Alfalfa | Carton or flat | 5 |
| | Bag | 5 |
| | Bag | 1 |
| Bean | Carton or film bag | 10 |
| | Carton | 6 |
| | Film bag | 5 |
| Radish | Various containers | 50 |
| | Carton or crate, 1½ bushel | 40 |
| | Various containers | 30 |
| | Various containers | 25 |
| | Carton | 20 |
| | Various containers | 20 |
| | Carton | 10 |
| | Various containers | 10 |
| | Various containers | 8 |
| | Carton | 5 |
| | Various containers | 4 |
| Squash | | |
| Summer | Container, bushel and 11/9 bushel | 42 |
| | Carton or crate | 35 |
| | Carton or crate, ¾ bushel | 30 |
| | Carton or lug (California, Mexico) | 26 |

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES (Continued)

| Vegetable | ${ m Container}^1$ | Approximate Net Weight (lb) ^{2, 3} |
|--------------|----------------------------|---|
| | | |
| | Container, ½ or 5% bushel | 21 |
| **** | Basket or carton, 8-q | 10 |
| Winter | Carton or crate, 1½ bushel | 50 |
| | Carton or crate | 40 |
| | Carton or crate | 35 |
| Strawberry | Flat, 12 1-pt baskets | 12 |
| | Flat, 6 1-qt baskets | 12 |
| | Flat, 12 10-oz clamshells | 7.5 |
| | Flat, 12 8.8-oz clamshells | 6.6 |
| | Crate, 8 16-oz clamshells | 9 |
| | Tray, $\frac{1}{2}$ | 5 |
| | Flat, 4 2-lb clamshells | 8 |
| Sweet potato | Carton | 40 |
| | Carton | 20 |
| | Carton | 10 |
| | Poly bag | 5 |
| | Poly bag | 3 |
| Taro | Carton, crate, or sack | 50 |
| | Carton | 10 |
| Tomatillo | Carton | 40 |
| | Carton | 30 |
| | Carton | 10 |
| Tomato | | |
| Round | Carton, loose | 25 |
| | Carton, flats | 20 |
| | Lug, 3-layer | |
| | Lug, 2-layer | |
| Cherry | Flat, 12 1-pt baskets | |
| Roma | Carton, loose 25 | |
| Greenhouse | Flat, 1 layer | 15 |
| Grape | Clamshells: 8, 12, 24-oz | |
| - | Containers, 12 1-pt | |
| | Containers, bulk | 20 |

TABLE 8.42. SHIPPING CONTAINERS FOR FRESH VEGETABLES (Continued)

| Vegetable | $\operatorname{Container}^1$ | Approximate Net Weight (lb) ^{2, 3} |
|--------------|--------------------------------------|---|
| | | (=.0) |
| Turnip | Basket or sack, bushel | 50 |
| Turnip | Carton, bunched | 40 |
| | Basket, carton, crate, bag; ½ bushel | 25 |
| | , , , | 25 20 |
| Watermelon | Carton, 12-count bunch Bulk | |
| watermeion | Bin | 45,000 |
| | | 1,050 |
| | Carton, various count | 85 |
| | Carton, seedless | 65 |
| | Carton, icebox | 35 |
| **** | Bins: 24, 30, and 36 in. | 200 |
| Winter melon | Bin | 800 |
| | Crate | 70 |
| | Carton, crate, or sack | 50 |
| | Various containers | 50 |
| | Various containers | 40 |
| | Various containers | 30 |
| | Various containers | 20 |
| | Various containers | 10 |
| Yucca | Carton, crate, or sack | 50 |
| | Various containers | 50 |
| | Various containers | 40 |
| | Various containers | 30 |
| | Various containers | 20 |
| | Various containers | 10 |
| | Cartons | 10 |

Adapted from *The Packer Sourcebook*, Vance Publishing Corp., 10901 W. 84th Terr., Lenexa, KS 66214-1632 (2004). Reprinted by permission from *The Packer The Packer* does not review or endorse products, services, or opinions.

 $^{^{1}}$ Other containers are being developed and used in the market place. The requirements of each market should be determined.

 $^{^2}$ Actual weights larger and smaller than those shown may be found. The midpoint of the range should be used if a single value is desired.

³Other weight as shown.

TABLE 8.43. STANDARDIZED SHIPPING CONTAINER DIMENSIONS DESIGNED FOR A 40 \times 48-INCH PALLET

| Outside Base Dimensions (in.) | Containers per Layer | Layers may be Cross-stacked |
|---|----------------------|--------------------------------|
| $15^{3}\!\!/_{\!\!4} 	imes 11^{3}\!\!/_{\!\!4}$ | 10 | Yes |
| $19^{3}\!/_{\!4}	imes11^{3}\!/_{\!4}$ | 8 | No |
| $19^{3}\hspace{-0.5mm}/_{4}	imes15^{3}\hspace{-0.5mm}/_{4}$ | 6 | No |
| $23^{3}\hspace{-0.5mm}/_{4}	imes15^{3}\hspace{-0.5mm}/_{4}$ | 5 | Yes |

Adapted from S. A. Sargent, M. A. Ritenour and J. K. Brecht, "Handling, Cooling, and Sanitation Techniques for Maintaining Postharvest Quality" in *Vegetable Production Handbook* (University of Florida, 2005–2006).

TABLE 8.45. TRANSPORT EQUIPMENT INSPECTION

Most carriers check their transport equipment before presenting it to the shipper for loading. The condition of the equipment is critical to maintaining the quality of the products. Therefore, the shipper also should check the equipment to ensure it is in good working order and meets the needs of the product. Carriers provide guidance on checking and operating the refrigeration systems.

All transportation equipment should be checked for:

- Cleanliness—the load compartment should be regularly steamcleaned.
- Damage—walls, floors, doors, ceilings should be in good condition.
- Temperature control—refrigerated units should be recently calibrated and supply continuous air circulation for uniform product temperatures.

Shippers should insist on clean equipment. A load of products can be ruined by:

- Odors from previous shipments
- Toxic chemical residues
- Insects nesting in the equipment
- · Decaying remains of agricultural products
- · Debris blocking drain openings or air circulation along the floor

Shipper should insist on well-maintained equipment and check for the following:

- Damage to walls, ceilings, or floors that can let in the outside heat, cold, moisture, dirt, and insects
- Operation and condition of doors, ventilation openings, and seals
- · Provisions for load locking and bracing

For refrigerated trailers and van containers, the following additional checks are important:

 With the doors closed, have someone inside the cargo area check for light—the door gaskets must seal. A smoke generator also can be used to detect leaks.

- The refrigeration unit should cycle from high to low speed when the desired temperature is reached and then back to high speed.
- Determine the location of the sensing element that controls the discharge air temperature. If it measures return air temperature, the thermostat may have to be set higher to avoid chilling injury or freezing injury of the products.
- A solid return air bulkhead should be installed at the front of the trailer.
- A heating device should be available for transportation in areas with extreme cold weather.
- Equipment with a top air delivery system must have a fabric air chute or metal ceiling duct in good condition.

Adapted from B. M. McGregor, Tropical Products Handbook, USDA Agr. Handbook 668 (1987).

VEGETABLE MARKETING

TABLE 8.46. CHARACTERISTICS OF DIRECT MARKETING ALTERNATIVES FOR FRESH VEGETABLES

| Grower Characteristics | Pick-Your-Own | Roadside Market | Farmer's Market |
|------------------------|---|--|--|
| Harvesting cost | Customer assumes the cost. | Usual cost. Henselly minimal for | Usual cost. Denends on grower's |
| Selling cost | Field attendant is needed. | produce. Checkout attendant is | distance to market. Checkout attendant is |
| 1 | Harvesting instructions should be provided. Advertising. | needed. Advertising. | needed. |
| Grower liability | Liable for accidents. Absorbs damages to property and crop. | Liable for accidents at market. | Owner of market is responsible. |
| Market investment | Containers. Locational signs. Available parking. | Building or stand. Available parking. Containers. | Usually parking or building space is rented. Containers. |

| Volume of produce desired | Enough for customer traffic demands. | Enough to visibly attract customers to stop. Variety is helpful | Enough to justify transportation and other costs. |
|--------------------------------|---|---|---|
| Prices received for produce | Often lower than other alternatives because transportation and harvesting cost is assumed by the customer. Producer | Producer sets the price given perceived demand competitive conditions. | Producer sets the price. There may be competition from other sellers. |
| Quality | sets the price. Can sell whatever the customers will pick. | Can classify produce and sell more than one grade. | Ability to sell may depend on the competing qualities available from other |
| Other | Balance between number of pickers and amount needing to be harvested sometimes is difficult to achieve. | Sometimes other items besides produce are sold to supplement income. Produce spoilage can be minimized if adequate cooling facilities are used. | growers. Sometimes other items besides produce are sold to supplement income. Bulk sales are sometimes recommended. |
| Advated from Progratit Dunding | Advated from Prisinkis Dudindion and Dus Manazamans Oblahoma Proconditio Betannian Pisanlan F 859 (1986) | in Detartion Giranlan F 959 (1002) | |

TABLE 8.47. CHARACTERISTICS OF SOME WHOLESALE MARKETING ALTERNATIVES FOR FRESH VEGETABLES

| > | VEGE IABLES | | | |
|--------------------------------|--|--|---|--|
| Grower Consideration | Terminal Market | Cooperative and Private Packing Facilities | Peddling to Grocer or Restaurant | Wholesale/Broker |
| Harvesting cost | Usual cost. | Sometimes harvesting equipment is | Usual cost. | Usual cost. |
| Transportation cost | Depends on distance to | provided. Sometimes transportation is | Depends on distance traveled. | Depends on prior arrangements for |
| Prices received for produce | Grower is usually the price taker. | Prices received by growers depend on market prices, costs, | Buyer and grower may compromise on price, or | Grower is usually the price taker. |
| Required | Usually large quantities are needed. | and revenues. Depends on the products to be sold. | grower fixes price. Depends on the size of outlets and route. | Usually large quantities are needed. |

| Depends on | arrangements. | Usually minimal | costs to grower. | Specialized | containers are | required. | Must meet standards | or U.S. grades so | produce can be | handled in bulk. | Good wholesaler/ | broker can sell | produce quickly at | good prices. A | long-term buyer/ | seller relationship | is desirable. | Broker does not | necessarily take | title of produce. | |
|--------------------------|-----------------------|-----------------|------------------|----------------|----------------|-----------|---------------------|-------------------|----------------|------------------|-----------------------|------------------------|--------------------|---------------------|--------------------|---------------------|--------------------|-----------------|------------------|-------------------|----------|
| Truck. Containers. | | | | | | | High quality is | needed. | | | Long-term outlet for | consistent quality. | Good price for | quality produce. | Difficult to enter | market and | develop | customers. | | | |
| Relatively low on a per- | unit basis. | | | | | | Must meet buyer's | standards or U.S. | grades. | | May provide technical | assistance to growers. | Firms help in | planning of growing | and selling. | Equipment may be | shared by growers. | | | | |
| Truck or some | ${ m transportation}$ | arrangements. | Specialized | containers are | required. | | Must meet | buyer's | standards or | U.S. grades. | Good source of | market | information. | Can move very | large | quantities at | one time. | Many buyers | are located at | terminal | markets. |
| Market | investment | | | | | | Quality | | | | Other | | | | | | | | | | |

Adapted from Cucurbit Production and Pest Management, Oklahoma Cooperative Extension Circular E-853 (1986).

ADDITIONAL SOURCES OF POSTHARVEST INFORMATION

- J. A. Bartz and J. K. Brecht, Postharvest Physiology and Pathology of Vegetables, 2nd ed. (New York: Marcel Dekker, 2003).
- A. A. Kader (ed.), *Postharvest Technology of Horticultural Crops* (University of California Agriculture and Natural Resource Publication 3211, 2002).
- S. J. Kays and R. E. Powell, Postharvest Biology (Athens, Ga.: Exon, 2004).
- A. L. Snowdon, A Color Atlas of Post-Harvest Disease and Disorders of Fruits and Vegetables, vol. 1, General Introduction and Fruits (Boca Raton, Fla.: CRC Press, 1990).
- A. L. Snowdon, A Color Atlas of Post-Harvest Disease and Disorders of Fruits and Vegetables, vol. 2, Vegetables (Boca Raton, Fla.: CRC Press, 1992).

PART 9 VEGETABLE SEEDS

- 01 SEED LABELS
- 02 SEED GERMINATION TESTS
- 03 SEED GERMINATION STANDARDS
- 04 SEED PRODUCTION
- 05 SEED YIELDS
- 06 SEED STORAGE
- 07 VEGETABLE VARIETIES
- 08 VEGETABLE SEED SOURCES

01 SEED LABELS

LABELING VEGETABLE SEEDS

Seeds entering into interstate commerce must meet the requirements of the Federal Seed Act. Most state seed laws conform to federal standards. However, the laws of the individual states vary considerably with respect to the kinds and tolerances for noxious weeds. The noxious weed seed regulations and tolerances, if any, may be obtained from the State Seed Laboratory of any state.

Vegetable seed in packets or in larger containers must be labeled in any form that is clearly legible with the following required information:

- *Kind, variety, and hybrid.* The name of the kind and variety and hybrid, if appropriate, must be on the label. Words or terms that create a misleading impression as to the history or characteristics of kind or variety may not be used.
- Name of shipper or consignee. The full name and address of either the shipper or consignee must appear on the label.
- Germination. Vegetable seeds in containers of 1 lb or less with germination equal to or more than the standards need not be labeled to show the percentage germination or date of test. Vegetable seeds in containers of more than 1 lb must be labeled to show the percentage of germination, the month and year of test, and the percentage of hard seed, if any.
- Lot number. The lot number or other lot identification of vegetable seed in containers of more than 1 lb must be shown on the label and must be the same as that used in the records pertaining to the same lot of seed.
- Seed treatment. Any vegetable seed that has been treated must be labeled in no smaller than 8-point type to indicate that the seed has been treated and to show the name of any substance used in such treatment.

Adapted from Federal Seed Act Regulations, http://www.ams.usda.gov/lsg/seed.htm.

02 SEED GERMINATION TESTS

TABLE 9.1. REQUIREMENTS FOR VEGETABLE SEED GERMINATION TESTS

| | | | | | Additiona | Additional Directions |
|------------------------|------------------------|--|-------------------------|--------------------------|--|--|
| Seed | $\mathrm{Substrata}^1$ | ${\rm Temperature}^2 \\ {\rm (^{\circ}F)}$ | First Count (Days) (| Final Count (Days) | Final Count (Days) Specific Requirements | Fresh and Dormant Seed |
| Artichoke | B, T | 98–89 | 7 | 21 | | |
| Asparagus | B, T, S | 98-89 | 7 | 21 | | |
| Asparagus bean Bean | B, T, S | 98-89 | 3 | 83 | | |
| Garden | B, T, S, TC | 68–86; 77 | none | 80 | | Use 0.3-0.6% |
| | | | | | | $Ca(NO_3)_2$ to |
| | | | | | | moisten substratum for retesting if |
| | | | | | | hypocotyl collar rot |
| | | | | | | is observed in |
| Lima | B, T, C, S | 98–89 | 2 | 93 | | mutal test. |
| Runner | B, T, S | 98-89 | 5 | 93 | | |
| Beet | B, T, S | 98-89 | က | 14 | Presoak seeds in | |
| | | | | | water for 2 hrs. | |

TABLE 9.1. REQUIREMENTS FOR VEGETABLE SEED GERMINATION TESTS (Continued)

| | | | | | Additional | Additional Directions |
|--------------------|---|----------------------------------|--------------------------|--------------------------|--|--|
| Seed | $\mathrm{Substrata}^{\scriptscriptstyle 1}$ | ${\rm Temperature}^2_{\rm (°F)}$ | First Count (Days) | Final Count (Days) | Specific Requirements | Fresh and Dormant Seed |
| Broad bean | S, C | 64 | 4 | 14^3 | | Prechill at 50° F for $3_{ m davs}$ |
| Broccoli | B, P, T | 98-89 | က | 10 | | Prechill at 41° or 50°F |
| Brussels sprouts | В, Р, Т | 98–89 | က | 10 | | for a days, KNO_3 and light. Prechill at 41° or 50° F for 3 days; KNO_3 |
| Burdock, great | B, T | 98–89 | 7 | 14 | | and light. |
| Cabbage | В, Р, Т | 98-89 | က | 10 | | Prechill at 41° or 50°F for 3 days; KNO ₃ |
| Cabbage, Chinese | B. T | 98-89 | က | 2 | | and ugue. |
| Cabbage, tronchuda | В, Р | 98-89 | က | 10 | | Prechill at 41° or 50°F for 3 days; KNO_3 and light. |
| Cantaloupe | B, T, S | 98-89 | 4 | 10 | Keep substratum on dry side; remove excess moisture. |) |

| Cardoon | B, T | 98-89 | | _ | | |
|-----------------|------------------|-----------|-------------|-----|--|---|
| Carrot | B, T | 98-89 | | # | | |
| Cauliflower | В, Р, Т | 98–89 | 3 10 | 0 | | Prechill at 41° or 50°F for 3 days; KNO ₃ and light. |
| Celeriac | Ь | 59–77; 68 | 10 21 | | Light; 750–1,250 lux from cool-white |) |
| | | | | | fluorescent source. | |
| Celery | Ъ | 59–77; 68 | 10 21 | | Light; 750–1,250 lux | |
| | | | | | from cool-white | |
| | ر ا | 000 | | | inacionation in the second sec | |
| Chard, Swiss | B, I, 3 | 08-80 | э <u>14</u> | | Fresoak seed in | |
| | | | | | water for 2 hrs. | |
| Chicory | P, TS | 98-89 | 5 14 | | Light; KNO ₃ or soil. | |
| Chives | B, T | 89 | 6 14 | | | |
| Citron | B, T | 98-89 | 7 14 | | Soak seeds 6 hrs. | Test at 86°F. |
| Collards | B. P. T | 98-89 | 3 10 | _ | | Prechill at 41° or 50°F |
| | ` | | | | | for 3 days; KNO_3 |
| | | | | | | and light. |
| Corn, sweet | B, T, S, TC, TCS | 68–86; 77 | 4 | 7 | | |
| Corn salad | B, T | 59 | 7 28 | ~ | | Test at 50°F. |
| Cowpea | B, T, S 68–86 | 98-89 | 52 | 883 | | |
| Cress Garden | БРЛ | 94 | 10 | _ | | I ich+ |
| Unland | , ; , d | 98–89 | | | Light: KNO. | Make first count |
| | ı | | | | | when necessary or desirable. |
| Water | Ь | 98-89 | 4 14 | | Light. | |
| | | | | | | |

TABLE 9.1. REQUIREMENTS FOR VEGETABLE SEED GERMINATION TESTS (Continued)

| | | | | | Additional | Additional Directions |
|----------------|---|--|--------------------------|--------------------------|--|--|
| Seed | $\mathrm{Substrata}^{\scriptscriptstyle 1}$ | ${\rm Temperature}^2 \\ ({}^\circ{\rm F})$ | First Count (Days) | Final Count (Days) | Specific Requirements | Fresh and Dormant Seed |
| Cucumber | B, T, S | 98-89 | က | 2 | Keep substratum on dry side; remove excess moisture. | |
| Dandelion | P, TB | 98-89 | 7 | 21 | Light, 750-1,250 lux. | |
| Dill | B, T | 98-89 | 7 | 21 | | |
| Eggplant | P, TB, RB, T | 98-89 | 7 | 14 | | Light; KNO ₃ . |
| Endive | P, TS | 98-89 | 5 | 14 | Light, KNO ₃ or soil. | |
| Fennel | B, T | 98-89 | 9 | 14 | | |
| Kale | B, P, T | 98-89 | က | 10 | | Prechill at 41° or 50° F |
| | | | | | | for 3 days; KNO_3 |
| Kale, Chinese | B, P, T | 98-89 | က | 10 | | Prechill at 41° or $50^{\circ}\mathrm{F}$ |
| | · · · · · · · · · · · · · · · · · · · | | | | | for 3 days; KNO_3 |
| Kale, Siberian | В, Р, Т | 68–86; 68 | က | 7 | | and ngm. |
| Kohlrabi | B, P, T | 98-89 | က | 10 | | Prechill at 41° or $50^{\circ}\mathrm{F}$ |
| | | | | | | for 3 days; $\mathrm{KNO_3}$ and light. |
| Leek | B, T | 89 | 9 | 14 | | |

| 0. | u 89 | none | 7 | Light. | Prechill at 50°F for 3 |
|-----------------------|-----------|------|--------|-----------------------------------|---|
| Ь | 98–89 | က | 7 | Light. | days or test at 59 F . Prechill at 50° F for 7 |
| | | | | | days and test for 5 additional days. |
| | 98-89 | က | 7 | | |
| B, T 68- | 98-89 | 4 | 14^3 | | |
| | | 9 | 10 | | |
| 89 88 | | 9 | 12 | | |
| | | 9 | 10 | | |
| | 98 | က | 7 | | |
| 3, T, TS 68–86 | 98 | 11 | 28 | | |
| | 98 | 9 | 28 | | |
| 3, T, S 68 | | 5 | 803 | | |
| rb, rb, T, B, P 68-86 | 9 | 9 | 14 | | Light and KNO ₃ . |
| B, T, S 68–86 | 3 | 4 | 7 | Keep substratum on | |
| | | | | dry side; remove excess moisture. | |
| B, T 68 | | 4 | 9 | | |
| TB, TS 68–86 | 91 | 7 | 21 | Light. | |
| | 9 | က | 14 | | |
| B, T, S 68–86 | 9 | 5 | 14 | | |
| 3, T 59 | | 5 | 10 | | Prechill at 50°F for 3 |
| | | | | | days. |
| 3, T 68–86 | 98 | 5 | 21 | | |
| P, TB, TS 68–86 | 98 | က | 14 | Light. | Test at 59°F. |
| C, TCS | 68–86; 77 | ī. | 83 | | |

TABLE 9.1. REQUIREMENTS FOR VEGETABLE SEED GERMINATION TESTS (Continued)

| | | | | | Additional | Additional Directions |
|----------------------------------|------------------------------|--|--------------------------|--------------------------|---|--|
| Seed | $\mathrm{Substrata}^1$ | First Temperature ² Count (°F) (Days) | First Count (Days) | Final Count (Days) | Specific Requirements | Fresh and Dormant Seed |
| Spinach | TB, T | 59, 50 | L | 21 | Keep substratum on dry side; remove | |
| Spinach, New Zealand | [- | 59, 68 | ಗು | 21 | Soak fruits overnight (16 hrs., air-dry 7 hrs.; plant in very wet towels, do not rewater unless later counts exhibit | On 21st day, scrape fruits and test for 7 additional days. |
| Squash | В, Т, S | 98-89 | 4 | 7 | Argest models of the control of the | |
| Tomato Tomato, husk Turnip | B, P, RB, T P, TB B. T | 98–89 98–89 98–89 | 3 - 2 | 14 28 7 | Light; KNO ₃ . | Light; KNO ₃ . |
| Watermelon | B, T, S | 68–86; 77 | 4 | 14 | Keep substratum on dry side; remove excess moisture. | Test at 86°F. |

Adapted from Association of Official Seed Analysts, Rules for Testing Seeds, Germination Tests, Methods of Testing for Laboratory Germination (2004), http:// www.aosaseed.com.

- 1 B = between blotters
- TB = top of blotters
- T = paper toweling, used either as folded towel tests or as roll towel tests in horizontal or vertical position
- S =sand or soil

 - $\Gamma S = top of sand or soil$
- C = creped cellulose paper wadding (0.3-in. thick Kimpak or equivalent) covered with a single thickness of blotter through which holes are punched for the seed that are pressed for about one-half their thickness into the paper wadding. with sand or soil

TC = on top of creped cellulose paper without a blotter

P = covered petri dishes: with 2 layers of blotters; with 1 layer of absorbent cotton; with 5 layers of paper toweling; with 3 thicknesses of filter paper; or

RB = blotters with raised covers, prepared by folding up the edges of the blotter to form a good support for the upper fold which serves as a cover, preventing the top from making direct contact with the seeds

Temperature. A single number indicates a constant temperature. Two numerals separated by a dash indicate an alternation of temperature; the test is to be counted as hard seed. If at the end of the germination period provided for legume and okra swollen seeds or seeds of these kinds that have just started to Hard seeds. Seeds that remain hard at the end of the prescribed test because they have not absorbed water, due to an impermeable seed coat, are to be germinate are still present, all seeds or seedlings except the above-stated shall be removed and the test continued for 5 additional days and the normal held at the first temperature for approximately 16 hrs and at the second temperature for approximately 8 hrs per day. seedlings included in the percentage of germination.

03 SEED GERMINATION STANDARDS

TABLE 9.2. GERMINATION STANDARDS FOR VEGETABLE SEEDS IN INTERSTATE COMMERCE

The following germination standards for vegetable seeds in interstate commerce, which are construed to include hard seed, are determined and established under the Federal Seed Act.

| Seed | % | Seed | % |
|-----------------------|----|------------------|----|
| Artichoke | 60 | Cress, garden | 75 |
| Asparagus | 70 | Cress, upland | 60 |
| Bean, asparagus | 75 | Cress, water | 40 |
| Bean, broad | 75 | Cucumber | 80 |
| Bean, garden | 70 | Dandelion | 60 |
| Bean, lima | 70 | Dill | 60 |
| Bean, runner | 75 | Eggplant | 60 |
| Beet | 65 | Endive | 70 |
| Broccoli | 75 | Kale | 75 |
| Brussels sprouts | 70 | Kale, Chinese | 75 |
| Burdock, great | 60 | Kale, Siberian | 75 |
| Cabbage | 75 | Kohlrabi | 75 |
| Cabbage, tronchuda | 70 | Leek | 60 |
| Cantaloupe | 75 | Lettuce | 80 |
| Cardoon | 60 | Mustard, India | 75 |
| Carrot | 55 | Mustard, spinach | 75 |
| Cauliflower | 75 | Okra | 50 |
| Celeriac | 55 | Onion | 70 |
| Celery | 55 | Onion, Welsh | 70 |
| Chard, Swiss | 65 | Pak choi | 75 |
| Chicory | 65 | Parsley | 60 |
| Chinese cabbage | 75 | Parsnip | 60 |
| Chives | 50 | Pea | 80 |
| Citron | 65 | Pepper | 55 |
| Collards | 80 | Pumpkin | 75 |
| Corn, sweet | 75 | Radish | 75 |
| Corn salad | 70 | Rhubarb | 60 |
| Cowpea (southern pea) | 75 | Rutabaga | 75 |

TABLE 9.2. GERMINATION STANDARDS FOR VEGETABLE SEEDS IN INTERSTATE COMMERCE (Continued)

| Seed | % | Seed | % |
|----------------|----|----------------------|----|
| Sage | 60 | Spinach, New Zealand | 40 |
| Salsify | 75 | Squash | 75 |
| Savory, summer | 55 | Tomato | 75 |
| Sorrel | 65 | Tomato, husk | 50 |
| Soybean | 75 | Turnip | 80 |
| Spinach | 60 | Watermelon | 70 |

Adapted from Federal Seed Act Regulations, http://www.ams.usda.gov/lsg/seed.htm(2005).

04 SEED PRODUCTION

TABLE 9.3. ISOLATION DISTANCES BETWEEN PLANTINGS OF VEGETABLES FOR OPEN-POLLINATED SEED PRODUCTION

Self-pollinated Vegetables

Self-pollinated crops have little outcrossing. Consequently, the only isolation necessary is to have plantings spaced far enough apart to prevent mechanical mixture at planting or harvest. A tall-growing crop is often planted between different varieties.

| Bean | Bean, lima | Chicory | Endive |
|---------|------------|---------|--------|
| Lettuce | Pea | Tomato | |

Cross-pollinated Vegetables

Cross-pollination of vegetables may occur by wind or insect activity. Therefore, plantings of different varieties of the same crop or different crops in the same family that can cross with each other must be isolated. Some general isolation guidelines are provided; however, the seed grower should follow the recommendations of the seed company for whom the seed is being grown.

| Wind-pollinated Vegetables | Distance (miles) |
|----------------------------|---|
| Beet | $^{1\!\!}/_{2}$ –2 5 from sugar beet or Swiss chard |
| Sweet corn | 1 |
| Spinach | $^{1}/_{4}$ -3 |
| Swiss chard | $\frac{3}{4}$ -5 5 for sugar beet or beet |

TABLE 9.3. ISOLATION DISTANCES BETWEEN PLANTINGS OF VEGETABLES FOR OPEN-POLLINATED SEED PRODUCTION (Continued)

| Insect-pollinated Vegetables | Distance (miles) |
|------------------------------|--------------------------------------|
| Asparagus | 1/4 |
| Broccoli | 1/2-3 |
| Brussels sprouts | 1/2-3 |
| Cabbage | 1/2-3 |
| Cauliflower | 1/2-3 |
| Collards | 3/4-3 |
| | 5 from other cole crops |
| Kale | 3/4-2 |
| | 5 from other cole crops |
| Kohlrabi | 1/2-3 |
| Carrot | 1/2-3 |
| Celeriac | 1 |
| Celery | 1 |
| Chinese cabbage | - 1 |
| Cucumber | 1½ for varieties |
| | ½ from other cucurbits |
| Eggplant | 1/4 |
| Gherkin | 1/4 |
| Leek | 1 |
| Melons | $1\frac{1}{2}$ -2 for varieties |
| 11010112 | ½ from other cucurbits |
| Mustard | 1 |
| Onion | 1–3 |
| Parsley | ¹ / ₂ –1 |
| Pepper | 1/2 |
| Pumpkin | 1½-2 for varieties |
| 1 umpkin | ½ from other cucurbits |
| Radish | 1/4-2 |
| Rutabaga | 1/4-2 |
| Spinach | ¹ / ₄ –2 |
| Squash | $1\frac{1}{2}$ 2 for varieties |
| Dqua511 | ½ from other cucurbits |
| Turnip | $\frac{1}{4}$ 170111 other cucurbits |

 $\label{eq:Adapted in part from Seed Production in the Pacific Northwest, Pacific Northwest Extension Publications (1985).$

TABLE 9.4. CONDITIONS FOR CLASSES OF CERTIFIED VEGETABLE SEED

Certified

Registered

Foundation

| Bean 1 | $Isolation^2$ | ${ m Field}^3$ | Seed^4 | $Land^1$ | $Land^1$ $Isolation^2$ $Field^3$ $Seed^4$ $Land^1$ $Isolation^2$ $Field^3$ $Seed^4$ $Land^1$ $Isolation^2$ $Field^3$ $Seed^4$ | ${ m Field}^3$ | Seed^4 | $Land^1$ | ${\rm Isolation}^2$ | ${ m Field}^3$ | See |
|----------------|---------------|----------------|-------------------|----------|---|----------------|-------------------|----------|---------------------|----------------|-----|
| | 0 | 2,000 | 0.05 | 1 | 0 | 1,000 | 0.1 | 1 | 0 | 400 | 0.2 |
| Bean, broad 1 | 0 | 2,000 | 0.05 | 1 | 0 | 1,000 | 0.1 | П | 0 | 200 | 0.2 |
| Bean, mung 1 | 0 | 1,000 | 0.1 | 1 | 0 | 200 | 0.2 | П | 0 | 200 | 0.5 |
| Corn, sweet — | | . 1 | I | I | | I | I | 0 | 099 | 1,000 | 0.5 |
| Okra 1 | 1,320 | 0 | 0 | 1 | 1,320 | 2,500 | 0.5 | 1 | 825 | 1,250 | 1.0 |
| Onion 1 | 5,280 | 200 | 0 | 1 | 2,640 | 200 | 0.5 | 1 | 1,320 | 200 | 1.0 |
| Pepper 1 | 200 | 0 | 0 | 1 | 100 | 300 | 0.5 | 1 | 30 | 150 | 1.0 |
| Southern pea 1 | 0 | 2,000 | 0.1 | 1 | 0 | 1,000 | 0.2 | 1 | 0 | 200 | 0.5 |
| Tomato 1 | 200 | 0 | 0 | 1 | 100 | 300 | 0.5 | 1 | 30 | 150 | 1.0 |
| Watermelon 1 | 2,640 | 0 | 0 | 1 | 2,640 | 0 | 0.5 | 1 | 1,320 | 200 | 1.0 |
| | | | | | | | | | | | |

www.ams.usda.gov/lsg/seed.htm.

¹Years that must elapse after destruction of a previous crop of the same kind.

²Distance in feet from any contaminating source, but sufficient to prevent mechanical mixture.

³Minimum number of plants in which one off-type plant is permitted.

⁴Maximum percentage of off-type seeds permitted in cleaned seed.

VEGETABLE SEED PRODUCTION WEBSITES

- Vegetable Seed Production, http://www.ag.ohio-state.edu/~seedsci/vsp01.html
- $\label{lem:vegetable} \begin{tabular}{ll} Vegetable Seed Production—Dry Seeds, http://www.ag.ohio-state.edu/\\ \sim &seedsci/vsp02.html \end{tabular}$
- Vegetable Seed Production—Wet Seeds, http://www.ag.ohio-state.edu/ $\sim\!\!\operatorname{seedsci/vsp03.html}$
- Onion Seed Production in California, http://www.anrcatalog.ucdavis.edu/pdf8008.pdf
- Cucurbit Seed Production in California, http://www.anrcatalog.ucdavis.edu/pdf7229.pdf
- Carrot Seed Production, http://www.ars.usda.gov/research/docs.htm?docid=5235
- Crop Profile for Table Beet Seed in Washington, http://www.ipmcenters.org/cropprofiles/docs/wabeetseed.html
- Crop Profile for Cabbage Seed in Washington, http://www.ipmcenters.org/cropprofiles/docs/wacabbageseed.html
- Crop Profile for Spinach Seed in Washington, http://www.ipmcenters.org/ cropprofiles/docs/waspinachseed.html
- Seed Production and Seed Sources of Organic Vegetables, http://edis.ifas.ufl.edu/hs227
- Investigation of Organic Seed Treatments for Spinach Disease Control, http://vric.ucdavis.edu/scrp/sum-koike.html

05 SEED YIELDS

TABLE 9.5. VEGETABLE SEED YIELDS¹

| Vegetable | Average Yield (lb/acre) | Range (lb/acre) |
|----------------------|----------------------------|-----------------|
| Asparagus | | |
| $o.p.^2$ | 925 | 380-2,800 |
| $\mathbf{F_1}$ | 500 | |
| \mathbf{F}_2 | 750 | |
| Bean, snap | 1,800 | 1,400-2,800 |
| Bean, lima | 2,220 | 1,500-3,000 |
| Beet | | |
| o.p. | 1,950 | 1,800-2,500 |
| $\mathbf{F_1}$ | 1,150 | 900-1,400 |
| Broccoli | | |
| o.p. | 725 | 350-1,000 |
| $\mathbf{F_1}$ | 375 | 250-500 |
| Brussels sprouts | | |
| o.p. | 900 | 800-1,000 |
| $\mathbf{F_1}$ | 425 | 250-600 |
| Cabbage | | |
| o.p. | 740 | 500-1,000 |
| $\mathbf{F_1}$ | 440 | 300-600 |
| Cantaloupe | | |
| o.p. | 420 | 350 - 500 |
| $\mathbf{F_1}$ | 225 | 175 - 300 |
| Carrot | | |
| o.p. | 840 | 500-1,000 |
| $\mathbf{F_1}$ | 450 | 200-800 |
| Cauliflower | | |
| o.p. | 540 | 350-1,000 |
| $\mathbf{F_1}$ | 175 | 100-250 |
| Celeriac | 1,200 | 800-2,000 |
| Celery | 835 | 500 - 1,200 |
| Chard, Swiss | 1,600 | 1,000-2,000 |
| Chicory | 500 | 400-600 |
| Chinese cabbage | | |
| o.p. | 900 | 800-1,000 |
| \mathbf{F}_{1}^{-} | 400 | 300-500 |

TABLE 9.5. VEGETABLE SEED YIELDS¹ (Continued)

| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Vegetable | Average Yield (lb/acre) | Range |
|---|---------------------|---------------------------------------|-------------|
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | 2,000 | 1,500-2,500 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | , | 4.040 | |
| $\begin{array}{c} \text{Cucumber} \\ \text{beit alpha} \\ \text{pickle} \\ \text{slicer} \\ \text{o.p.} \\ \text{f.}_1 \\ \text{290} \\ \text{200-550} \\ \text{Eggplant} \\ \text{o.p.} \\ \text{f.}_1 \\ \text{290} \\ \text{200-550} \\ \text{Eggplant} \\ \text{o.p.} \\ \text{f.}_1 \\ \text{500} \\ \text{400-625} \\ \text{Endive} \\ \text{735} \\ \text{650-800} \\ \text{Florence fennel} \\ \text{o.p.} \\ \text{f.}_1 \\ \text{700} \\ \text{600-800} \\ \text{Kale} \\ \text{o.p.} \\ \text{f.}_1 \\ \text{700} \\ \text{600-800} \\ \text{Kale} \\ \text{o.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Kohlrabi} \\ \text{o.p.} \\ \text{f.}_1 \\ \text{450} \\ \text{400-500} \\ \text{Leek} \\ \text{o.p.} \\ \text{f.}_1 \\ \text{300} \\ \text{200-400} \\ \text{Lettuce} \\ \text{600} \\ \text{Mustard} \\ \text{1,325} \\ \text{1,300-1,350} \\ \text{New Zealand spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohra} \\ \text{Op.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{O.p.} \\ \text{f.}_1 \\ \text{650} \\ \text{600-700} \\ \text{Ohraphical spinach} \\ \text{600-700} \\ Ohr$ | | · · · · · · · · · · · · · · · · · · · | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | = | 1,100 | 400–1,700 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | 450 | 250 550 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | - | 650 | 450-850 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | 500 | 075 600 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | - | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 290 | 200-550 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | 640 | 500 775 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | _ | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | 199 | 030-000 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | 1 500 | 1 000-2 000 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 100 | 000 000 |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 1.100 | 1.000-1.200 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 333 | 000 100 |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 875 | 850-900 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 625 | 500-850 |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 300 | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 600 | 450-800 |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | Mustard | 1,325 | 1,300-1,350 |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | New Zealand spinach | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | _ | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | o.p. | 1,600 | 1,200-2,000 |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | _ | 650 | 600-700 |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | Onion | | |
| Parsley 900 600-1,200 Parsnip 975 600-1,300 | o.p. | 690 | 575-900 |
| Parsley 900 600-1,200 Parsnip 975 600-1,300 | | 450 | 350 - 550 |
| Parsnip 975 600–1,300 | | 900 | 600-1,200 |
| Pea 2,085 1,000–3,000 | Parsnip | 975 | 600-1,300 |
| | Pea | 2,085 | 1,000-3,000 |

TABLE 9.5. VEGETABLE SEED YIELDS¹ (Continued)

| Vegetable | Average Yield (lb/acre) | Range |
|-----------------------------|----------------------------|-------------|
| | | |
| Pepper | | |
| o.p. | 170 | 100-300 |
| $\mathbf{F_1}$ | 125 | 100-150 |
| Pumpkin | | |
| o.p. | 575 | 300-850 |
| \mathbf{F}_1 | 300 | 235 - 400 |
| Radish | | |
| o.p. | 1,200 | 600-2,000 |
| $\overline{\mathbf{F}_{1}}$ | 525 | 200-1,000 |
| Rutabaga | 2,200 | 1,800-2,500 |
| Salisfy | 800 | 600-1,000 |
| Southern pea | 1,350 | 1,200-1,500 |
| Spinach | • | , , |
| o.p. | 1,915 | 1,000-2,500 |
| \mathbf{F}_{1}^{-} | 1,100 | 1,000-1,200 |
| Squash, summer | • | , , |
| o.p. | 760 | 400-1,200 |
| \mathbf{F}_{1} | 360 | 250-425 |
| Squash, winter | | |
| o.p. | 620 | 300-1,200 |
| \mathbf{F}_{1} | 310 | 200-400 |
| Tomatillo | 600 | 500-700 |
| Tomato | | |
| \mathbf{F}_{1} | 125 | 75-170 |
| Turnip | | |
| o.p. | 2,300 | 2,000-3,000 |
| F ₁ | 1,350 | 1,200-1,500 |
| Watermelon | _,-, | _,, |
| o.p. | 405 | 350-600 |
| F ₁ | 220 | 190–245 |
| Triploid (seedless) | 40 | 20-70 |

¹ Yields are from information provided by representations of several major seed companies. Yields of some hybrids may be very much lower because of difficulties of seed production.

²o.p. = open pollinated

 F_1 = first-generation hybrid F_2 = second-generation hybrid

06 SEED STORAGE

STORAGE OF VEGETABLE SEEDS

High moisture and temperature cause rapid deterioration in vegetable seeds. The control of moisture and temperature becomes more important the longer seeds are held. Low moisture in the seeds means longer life, especially if they must be held at warm temperatures. Kinds of seeds vary in their response to humidity.

The moisture content of seeds can be lowered by drying them in moving air at 120°F. This may be injurious to seeds with an initial moisture content of 25–40%. With such seeds, 110°F is preferred. It may require less than 1 hr to reduce the moisture content of small seeds or up to 3 hr for large seeds. The difference depends on the depth of the layer of seeds, the volume of air, dryness of air, and original moisture content of seed. When seeds cannot be dried in this way, seal them in airtight containers over, but not touching, some calcium chloride. Use enough calcium chloride so that the moisture absorbed from the seeds produces no visible change in the chemical. Dried silica gel can be used in place of the calcium chloride.

Bean and okra may develop hard seeds if their moisture content is lowered to 7% or below. White-seeded beans are likely to become hard if the moisture content is reduced to about 10%. Dark-colored beans can be dried to less than 10% moisture before they become hard. Hard seeds do not germinate satisfactorily.

The moisture content of seed reaches an equilibrium with the atmosphere after a period of about 3 weeks for small seeds and 3–6 weeks for large seeds.

Storage temperatures near 32°F are not necessary. Between 40 and 50°F is quite satisfactory when the moisture content of the seed is low.

If the moisture content is reduced to 4-5% and the seeds put in sealed containers, a storage temperature of about $70^{\circ}F$ will be satisfactory for more than 1 year.

The 5-month limitation on the date of test does not apply when the following conditions are met:

- a. The seed was packaged within 9 months after harvest.
- b. The container does not allow water vapor penetration through any wall or seal greater than 0.05 g water per 100 sq in. of surface at 100°F with a relative humidity on one side of 90% and on the other side of 0%.

- c. The seed in the container does not exceed the percentage of moisture, on a wet weight basis, as listed in the table.
- d. The container is conspicuously labeled in not less than 8-point type with the information that the container is hermetically sealed, that the seed is preconditioned as to moisture content, and the calendar month and year in which the germination test was completed.
- e. The percentage pf germination of vegetable seed at the time of packaging was equal or above Federal Standards for Germination (see pages 512–513).

TABLE 9.6. STORAGE OF VEGETABLE SEEDS IN HERMETICALLY SEALED CONTAINERS

| Vegetable | Moisture (%) | Vegetable | Moisture (%) |
|------------------|--------------|----------------|--------------|
| Bean, garden | 7.0 | Lettuce | 5.5 |
| Bean, lima | 7.0 | Melon | 6.0 |
| Beet | 7.5 | Mustard, India | 5.0 |
| Broccoli | 5.0 | Onion | 6.5 |
| Brussels sprouts | 5.0 | Onion, Welsh | 6.5 |
| Cabbage | 5.0 | Parsley | 6.5 |
| Carrot | 7.0 | Parsnip | 6.0 |
| Cauliflower | 5.0 | Pea | 7.0 |
| Celeriac | 7.0 | Pepper | 4.5 |
| Celery | 7.0 | Pumpkin | 6.0 |
| Chard, Swiss | 7.5 | Radish | 5.0 |
| Chinese cabbage | 5.0 | Rutabaga | 5.0 |
| Chives | 6.5 | Spinach | 8.0 |
| Collards | 5.0 | Squash | 6.0 |
| Cucumber | 6.0 | Sweet corn | 8.0 |
| Eggplant | 6.0 | Tomato | 5.5 |
| Kale | 5.0 | Turnip | 5.0 |
| Kohlrabi | 5.0 | Watermelon | 6.5 |
| Leek | 6.5 | All others | 6.0 |

 $A dapted\ from\ Federal\ Seed\ Act\ Regulations, \ http://www.ams.usda.gov/lsg/seed/seed_pub.htm\ (2005).$

07 VEGETABLE VARIETIES

NAMING AND LABELING OF VEGETABLE VARIETIES

Every year, many new varieties of vegetable seed reach the U.S. marketplace. New varieties, when added to those already on the market, provide growers with a wide selection of seed. But, in order for them to buy intelligently, seed must be correctly named and labeled.

Marketing a product by its correct name might seem the most likely way to do business. However, USDA seed officials have found that seed, unfortunately, is sometimes named, labeled, or advertised improperly as it passes through marketing channels.

Marketing seed under the wrong name is misrepresentation. It can lead to financial loss for several participants in the seed marketing chain.

The grower, for example, buys seed to achieve specific objectives such as increased yield, competitiveness in a specialized market, or adaptability to growing conditions of a specific region. If seed is misrepresented and the grower buys seed other than he or she intended, the harvest may be less valuable than anticipated—or, worse yet, there may not even be a market for the crop.

In one case, a grower bought seed to grow cabbage to be marketed for processing into sauerkraut. As the cabbage matured, he found his crop was not suitable for processing and, even worse, that there was no market for the cabbage in his fields. In this case, improper variety labeling brought about financial hardship.

Seed companies and plant breeders also suffer in a market where problems with variety names exist. For instance, if the name of a newly released variety is misleading or confusing to the potential buyer, the variety may not attract the sales that it might otherwise.

This section outlines requirements for naming vegetable seed. It is based on the Federal Seed Act, a truth-in-labeling law intended to protect growers and home gardeners who purchase seed. Exceptions to the basic rules and the do's and don'ts of seed variety labeling and advertising also are explained.

WHO NAMES NEW VARIETIES

The originator or discoverer of a new variety may give that variety a name. If the originator or discoverer can't or chooses not to name a variety,

someone else may give that variety a name for marketing purposes. In such a case, the name first used when the seed is introduced into commerce is the name of the variety.

It is illegal to change a variety name once the name is legally assigned. In other words, a buyer may not purchase seed labeled as variety X and resell it as variety Y. An exception to this rule occurs when the original name is determined to be illegal. In such an instance, the variety must be renamed according to the rules mentioned above. Another exception applies to a number of varieties that were already being marketed under several names before 1956. (See section on synonyms.)

WHAT'S IN A NAME

To fully understand what goes into naming a variety, you need to know the difference between a *kind* of seed and a *variety*. *Kind* is the term used for the seed of one or more related plants known by a common name, such as carrot, radish, tomato, or watermelon.

Variety is a subdivision of kind. A variety has different characteristics from another variety of the same kind of seed—for example, "Oxheart" carrot and "Danvers 126" carrot or "Charleston Gray" and "Mickylee" watermelon.

The rules for naming plants relate to both kinds and varieties of seed:

- A variety must be given a name unique to the kind of seed to which it belongs. For instance, there can only be one variety of squash called "Dividend."
- 2. Varieties of two or more kinds of seed may have the same name if the kinds are not closely related. For example, there could be a "Dividend" squash and a "Dividend" tomato because squash and tomato are kinds of seed not closely related. On the other hand, it would not be permissible to have a "Dividend" squash and a "Dividend" pumpkin because the two kinds of seed are closely related.
- 3. Once assigned to a variety, the name remains exclusive. Even if "Dividend" squash has not been marketed for many years, a newly developed and different squash variety can't be given the name "Dividend" unless the original owner agrees to withdraw "Dividend" squash.
- 4. A company name may be used in a variety name as long as it is part of the original, legally assigned name. Once part of a legal variety name, the company name must be used by everyone, including another company that might market the seed.

When a company name is not a part of the variety name, it should not be used in any way that gives the idea that it *is* part of the variety name. For example, Don's Seed Company can't label or advertise "Dividend" squash variety as "Don's Dividend" because "Don's" may be mistaken to be part of the variety name.

The simplest way to avoid confusion is to separate the company and variety names in advertising or labeling.

- 5. Although the USDA discourages it, you may use descriptive terms in variety names as long as such terms are not misleading. "X3R," for instance, is accepted among pepper growers as meaning "Bacterial Leaf Spot, Race 1, 2, 3 resistant." It would be illegal to include "X3R" as part of a variety name if that variety were not "X3R" resistant. Similarly, if a cantaloupe variety is named "Burpee Hybrid PMT," the name would be illegal if the variety were not tolerant of powdery mildew.
- 6. A variety name should be clearly different in spelling and in sound. "Alan" cucumber would not be permissible if an "Allen" cucumber were already on the market.

HYBRIDS

Remember that a hybrid also is a variety. Hybrid designations, whether they are names or numbers, also are variety names. Every rule discussed here applies to hybrid seed as well as to nonhybrid seed.

In the case of hybrids, however, the situation is potentially more complex because more than one seed producer or company might use identical parent lines in producing a hybrid variety. One company could then produce a hybrid that was the same as one already introduced by another firm.

When this happens, both firms must use the same name because they are marketing the same variety.

If the people who developed the parent lines give the hybrid variety a name, that is the legal name. Otherwise, the proper name is the one given by the company that first introduced the hybrid seed into commerce.

USDA seed regulatory officials believe the following situation occurs far too often:

- 1. State University releases hybrid corn parent lines A and B.
- John Doe Seed Company obtains seed lines of A and B, crosses the
 two lines, and is the first company to introduce the resulting hybrid
 into commerce under a variety name. John Doe Seed Company names
 this hybrid "JD 5259."

3. La Marque Seeds, Inc., obtains lines A and B, makes the same cross, and names the resulting hybrid variety "SML 25." There has been no change in the A and B lines that would result in a different variety. La Marque ships the hybrid seed, labeled "SML 25," in interstate commerce, and violates the Federal Seed Act because the seed should have been labeled "JD 5259."

SYNONYMS—VARIETIES WITH SEVERAL NAMES

As noted earlier, the name originally assigned to a variety is the name that must be used forever. It can't be changed unless it is illegal.

This does not mean that all varieties must be marketed under a single name. In fact, some old varieties may be marketed legally under more than one name. If several names for a single variety of a vegetable seed were in broad general use before July 28, 1956, those names still may be used.

Here are some examples:

The names "Acorn," "Table Queen," and "Des Moines" have been known for many years to represent a single squash variety. They were in broad general use before July 28, 1956, so seed dealers may continue to use these names interchangeably.

With the exception of old varieties with allowable synonym names, all vegetable and agricultural varieties may have *only one* legally recognized name, and that name must be used by anyone who represents the variety name in labeling and advertising. This includes interstate seed shipments and seed advertisements sent in the mail or in interstate or foreign commerce.

IMPORTED SEED

Seed imported into the United States can't be renamed if the original name of the seed is in the Roman alphabet.

For example, cabbage seed labeled "Fredrikshavn" and shipped to the United States from Denmark can't be given a different variety name such as "Bold Blue"

Seed increased from imported seed also can't be renamed. If "Fredrikshavn" were increased in the United States, the resulting crop still couldn't be named "Bold Blue."

Seed with a name that is not in the Roman alphabet must be given a new name. In such a case, the rules for naming the variety are the same as stated previously.

BRAND NAMES

USDA officials have found evidence of confusion over the use of variety names and brand or trademark names. This includes names registered with the Trademark Division of the U.S. Patent Office.

Guidelines:

- The brand or trademark name must be clearly identified as being other than part of the variety name.
- 2. A brand name must never take the place of a variety name.
- 3. If a brand or trademark name is part of a variety's name, that trademark loses status. Anyone marketing the variety under its name is required to use the exact, legal variety name, including brand or trademark.

SUMMARY

If the naming, labeling, and advertising of a seed variety is truthful, it is probably in compliance with the Federal Seed Act.

Keep these simple rules in mind to help eliminate violations and confusion in the marketing of seed:

- · Research the proposed variety name before adopting it.
- Make sure the name cannot be confused with company names, brands, trademarks, or names of other varieties of the same kind of seed.
- Never change the variety name, whether marketing seed obtained from another source or from your own production—for example, hybrid seed that already has a legal name.

Adapted from Seed Regulatory and Testing Programs, http://www.ams.usda.gov/lsg/seed/facts.htm.

SELECTION OF VEGETABLE VARIETIES

Selection of the variety (technically, *cultivar*) to plant is one of the most important decisions the commercial vegetable grower must make each season. Each year, seed companies and experiment stations release dozens of new varieties to compete with those already available. Growers should evaluate some new varieties each year on a trial basis to observe

performance on their own farms. A limited number of new varieties should be evaluated so that observations on plant performance and characteristics and yields can be noted and recorded. It is relatively easy to establish a trial but time-consuming to make all the observations necessary to make a decision on adoption of a new variety. Some factors to consider before adopting a variety follow:

- Yield: The variety should have the potential to produce crops at least equivalent to those already grown. Harvested yield is usually much less than potential yield because of market restraints.
- Disease resistance: The most economical and effective means of pest management is through the use of varieties with genetic resistance to disease. When all other factors are about equal, it is prudent to select a variety with the needed disease resistance.
- Horticultural quality: Characteristics of the plant habit as related to climate and production practices and of the marketed plant product must be acceptable.
- Adaptability: Successful varieties must perform well under the range of environmental conditions usually encountered on the individual farm.
- Market acceptability: The harvested plant product must have characteristics desired by the packer, shipper, wholesaler, retailer, and consumer. Included among these qualities are packout, size, shape, color, flavor, and nutritional quality.

During the past few years there has been a decided shift to hybrid varieties in an effort by growers to achieve earliness, higher yields, better quality, and greater uniformity. Seed costs for hybrids are higher than for open-pollinated varieties because seed must be produced by controlled pollination of the parents of the hybrid.

Variety selection is a dynamic process. Some varieties retain favor for many years, whereas others are used only a few seasons if some special situation, such as plant disease or marketing change, develops. If a variety was released by the USDA or a university, many seed companies may carry it. Varieties developed by a seed company may be available only from that source, or may be distributed through many sources.

The Cooperative Extension Service in most states publishes annual or periodic lists of recommended varieties. These lists are usually available in county extension offices.

Adapted from D. N. Maynard, "Variety Selection," in Stephen M. Olson and Eric Simonne (eds.), Vegetable Production Handbook for Florida. (Gainesville, Fla.: Florida Cooperative Extension Service, 2004–2005), 17, http://edis.ifas.ufl.edu/CV102.

08 VEGETABLE SEED SOURCES

SOME SOURCES OF VEGETABLE SEEDS¹

-A-

Abbott & Cobb

P.O. Box 307 Feasterville, PA 10953-0307 Ph (215) 245-6666 Fax (215) 245-9043 http://www.acseed.com

Abundant Life Seeds

P.O. Box 157 Saginaw, OR 97472 Ph (541) 767-9606 Fax (866) 514-7333 http://www.abundantlifeseeds.com

American Takii, Inc.

301 Natividad Road Salinas, CA 93906 Ph (831) 443-4901 Fax (831) 443-3976 http://www.takii.com

Arkansas Valley Seed Solutions

4625 Colorado Boulevard Denver, CO 80216 Ph (877) 957-3337 Fax (303) 320-7516 http://www.seedsolutions.com -B-

Bakker Brothers USA

P.O. Box 519 Caldwell, ID 83606 Ph (208) 459-4420 Fax (208) 459-4457 http://www.bakkerbrothers.nl

Baker Creek Heirloom Seeds

2278 Baker Creek Road Mansfield, MO 65704 Ph (417) 924-8917 Fax (417) 924-8887 http://www.rareseeds.com

Bejo Seeds, Inc.

1972 Silver Spur Place Oceano, CA 93445 Ph (805) 473-2199 http://www.bejoseeds.com

BHN Seed

P.O. Box 3267 Immokalee, FL 34142 Ph (239) 352-1100 Fax (239) 352-1981 http://www.bhnseed.com

Bonanza Seeds International,

Inc.

3818 Railroad Avenue Yuba City, CA 95991 Ph (530) 673-7253 Fax (530) 673-7195 http://www.bonanzaseeds.com

Bountiful Gardens Seeds

18001 Shafer Ranch Road Willits, CA 95490-9626 Ph (707) 459-6410 Fax (707) 459-1925 http://www.bountifulgardens.org

W. Brotherton Seed Co., Inc.

P.O. Box 1136 Moses Lake, WA 98837 Ph (509) 765-1816 Fax (509) 765-1817 http://www.vanwaveren.de/uk/mitte/brotherton.htm

Bunton Seed Co.

939 E. Jefferson Street Louisville, KY 40206 Ph (800) 757-7179 Fax (502) 583-9040 http://www.buntonseed.com

Burgess Seed & Plant Co.

905 Four Seasons Road Bloomington, IL 61701 Ph (309) 622-7761 http://www.eburgess.com

W. Atlee Burpee & Co.

300 Park Avenue Warminster, PA 18974 Ph (800) 333-5808 Fax (800) 487-5530 http://www.burpee.com

-C-

California Asparagus Seed

2815 Anza Avenue Davis, CA 95616 Ph (530) 753-2437 Fax (530) 753-1209 http://www.calif-asparagus-seed.com

Carolina Gourds and Seeds

259 Fletcher Avenue Fuquay Varina, NC 27526 Ph (919) 577-5946 http://www.carolinagourdsandseeds. com

Champion Seed Co.

529 Mercury Lane Brea, CA 92621-4894 Ph (714) 529-0702 Fax (714) 990-1280 http://www.championseed.com

Chesmore Seed Co.

P.O. Box 8368 St. Joseph, MO 64508-8368 Ph (816) 279-0865 Fax (816) 232-6134 http://www.chesmore.com

Alf Chrisianson Seed Co.

P.O. Box 98 Mount Vernon, WA 98273 Ph (360) 366-9727 Fax (360) 419-3035 http://www.chriseed.com

Clifton Seed Company

P.O. Box 206 Faison, NC 28341 Ph (800) 231-9359 Fax (910) 267-2692 http://www.cliftonseed.com

Comstock, Ferre & Co.

263 Main Street Wethersfield, CT 06109 Ph (860) 571-6590 Fax (860) 571-6595 http://www.comstockferre.com

The Cook's Garden

PO Box 6530 Warminster, PA 18974 Ph (800) 457-9703 http://www.cooksgarden.com

Corona Seeds Worldwide

590-F Constitution Avenue Camarillo, CA 93012 Ph (805) 388-2555 Fax (805) 445-8344 http://www.coronaseeds.com

Crookham Co.

P.O. Box 520 Caldwell, ID 83606-0520 Ph (208) 459-7451 Fax (208) 454-2108 http://www.crookham.com

Crop King Inc.

5050 Greenwich Road Seville, OH 44273-9413 Ph (330) 769-2002 Fax (330) 769-2616 http://www.cropking.com

Cutter Asparagus Seed

516 Young Avenue Arbuckle, CA 95912 Ph (530) 475-3647 Fax (953) 476-2422 http://www.asparagusseed.com

-D-

DeRuiter Seeds, Inc.

13949 W. Colfax Avenue Building No. 1, Suite 220 Lakewood, CO 80401 Ph (303) 274-5511 Fax (303) 274-5514 http://www.deruiterusa.com

Dominion Seed House

P.O. Box 2500 Georgetown, ONT Canada L7G 4A2 Ph (905) 873-3037 Fax (800) 282-5746 http://www.dominion-seed-house.com

-E-

Elsoms Seeds Ltd.

Pinchbeck Road Spalding Lincolnshire PE11 1QG England, UK Ph 0 1775 715000 Fax 0 1775 715001 http://www.elsoms.com

Enza Zaden

7 Harris Place Salinas, CA 93901 Ph (831) 751-0937 Fax (831) 751-6103 http://www.enzazaden.nl/site/uk/

 $-F_-$

Farmer Seed & Nursery Co.

Division of Plantron, Inc. 818 NW Fourth Street Faribault, MN 52201 Ph (507) 334-1623 http://www.farmerseed.com

Henry Field Seed & Nursery Co.

P.O. Box 397 Aurora, IN 47001-0397 Ph (513) 354-1494 Fax (513) 354-1496 http://www.henryfields.com

Germania Seed Co.

P.O. Box 31787 Chicago, IL 60631 Ph (800) 380-4721 Fax (800) 410-4721 http://www.germaniaseed.com

Fred C. Gloeckner & Co., Inc.

600 Mamaroneck Avenue Harrison, NY 10528-1631 Ph (800) 345-3787 Fax (914) 698-2857 http://www.fredgloeckner.com

Golden Valley Seed

P.O. Box 1600 El Centro, CA 92243 Ph (760) 337-3100 Fax (760) 337-3135 http://www.goldenvalleyseed.com

Gurney's Seed & Nursery Co.

P. O. Box 4178 Greendale, IN 47025-4178 Ph (513) 354-1492 Fax (513) 354-1493 http://www.gurneys.com

-H-

Harris Moran Seed Co.

P.O. Box 4938 Modesto, CA 95352 Ph (209) 579-7333 Fax (209) 527-8684 http://www.harrismoran.com

Harris Seeds

P.O. Box 24966 Rochester, NY 14624-0966 Ph (800) 544-7938 Fax (877) 892-9197 http://www.harrisseeds.com

The Chas. C. Hart Seed Co.

P.O. Box 9169 Wethersfield, CT 06109 Ph (860) 529-2537 Fax (860) 563-7221 http://www.hartseed.com

Hazera Genetics Ltd.

2255 Glades Road, Suite 123A Boca Raton, FL 33431 Ph (561) 988-1315 Fax (561) 988-1319 http://www.hazera.co.il/

Heirloom Seeds

P.O. Box 245 West Elizabeth, PA 15088-0245 Ph (412) 384-0852 http://www.heirloomseeds.com

Hollar and Company, Inc.

P.O. Box 106 Rocky Ford, CO 81067 Ph (719) 254-7411 Fax (719) 254-3539 http://www.hollarseeds.com

Hydro-Gardens, Inc.

P.O. Box 25845 Colorado Springs, CO 80932 Ph (800) 936-5845 Fax (888) 693-0578 http://www.hydro-gardens.com

-K-

Illinois Foundation Seeds, Inc.

P.O. Box 722 Champaign, IL 61824-0722 Ph (217) 485-6260 Fax (217) 485-3687 http://www.ifsi.com

-J-

Jersey Asparagus Farms, Inc.

105 Porchtown Road Pittsgrove, NJ 08318 Ph (856) 358-2548 Fax (856) 358-6127 http://www.jerseyasparagus.com

Johnny's Selected Seeds

955 Benton Avenue Winslow, ME 04901 Ph (866) 838-1073 http://www.johnnyseeds.com

Jordan Seeds, Inc.

6400 Upper Aston Road Woodbury, MN 55125 Ph (651) 738-3422 Fax (651) 731-7690 http://www.jordanseeds.com

J. W. Jung Seed Co.

335 S. High Street Randolph, WI 53957-0001 Ph (800) 247-5864 Fax (800) 692-5864 http://www.jungseed.com

Keithly-Williams Seeds

P.O. Box 177 Holtville, CA 92250 Ph (800) 533-3465 Fax (760) 356-2409 http://www.keithlywilliams.com

Known-You Seed Co., Ltd.

26, Chung Cheng 2nd Road Kaohsiung, Taiwan Republic of China http://www.knownyou.com

-L-

Livingston Seed Co.

880 Kinnear Road Columbus, OH 43212 Ph (614) 488-1163 Fax (614) 488-4857 http://www.livingstonseed.com

-M-

Earl May Seed & Nursery Co.

208 N. Elm Street Shenandoah, IA 51603 Ph (712) 246-1020 Fax (712) 246-1760 http://www.earlmay.com

Mesa Maize Co.

60936 Falcon Road Olathe, CO 81425 http://www.mesamaize.com

McFayden Seed Co., Ltd.

30 Ninth Street Brandon, Manitoba Canada, R7A 6A6 Ph (800) 205-7111 http://www.mcfayden.com

Henry F. Michell Co.

P.O. Box 60160 King of Prussia, PA 19406-0160 Ph (800) 422-4678 http://www.michells.com

Monsanto Company

800 N. Lindbergh Boulevard St. Louis, MO 63167 Ph (314) 694-1000 http://www.monsanto.com

Mushroompeople

P.O. Box 220 Summertown, TN 38483-0220 Ph (800) 692-6329 Fax (800) 386-4496 http://www.mushroompeople.com

-N-

Native Seeds/SEARCH

526 N. Fourth Avenue Tucson, AZ 85705-8450 Ph (520) 622-5561 Fax (520) 622-5591 http://www.nativeseeds.org

New England Seed Co.

3580 Main Street Hartford, CT 06120 Ph (800) 825-5477 Fax (877) 229-8487 http://www.neseed.com

Nichol's Garden Nursery

1190 Old Salem Road NE Albany, OR 97321-4580 Ph (800) 422-3985 Fax (800) 231-5306 http://www. nicholsgardennursery.com

Nirit Seeds Ltd.

Moshav Hadar-Am 42935 Israel Ph (972) 9 832 24 35 Fax (972) 9 832 24 38 http://www.niritseeds.com

NK Lawn & Garden Co.

P.O. Box 24028 Chattanooga, TN 37422-4028 Ph (800) 328-2402 Fax (423) 697-8001 http://www.nklawnandgarden.com

Nourse Farms, Inc.

41 River Road South Deerfield, MA 01373 Ph (413) 665-2658 Fax (413) 665-7888 http://www.noursefarms.com

Nunhems Seed

P.O. Box 18 Lewisville, ID 83431 Ph (208) 754-8666 Fax (208) 754-8669 http://www.nunhems.com

OSC

Box 7 Waterloo, Ontario Canada N2J 3Z9 Ph (519) 886-0557 Fax (519) 886-0605 http://www.oscseeds.com

Oriental Vegetable Seeds

Evergreen Y. H. Enterprises P.O. Box 17538 Anaheim, CA 92817 Ph (714) 637-5769 http://www.evergreenseeds.com

Ornamental Edibles

5723 Trowbidge Way San Jose, CA 95138 Ph (408) 528-7333 Fax (408) 532-1499 http://www.ornamentaledibles.com

Orsetti Seed Co., Inc.

2301 Technology Parkway P.O. Box 2350 Hollister, CA 95023 Ph (831) 636-4822 Fax (831) 636-4814 http://www.orsettiseed.com

Outstanding Seed Company

354 Center Grange Road Monaca, PA 15061 Ph (800) 385-9254 http://www.outstandingseed.com

D. Palmer Seed Co., Inc.

8269 S. Highway 95 Yuma, AZ 85365 Ph (928) 341-8494 Fax (928) 341-8496 http://www.dpalmerseed.com

Paramount Seeds, Inc.

P.O. Box 1866 Palm City, FL 34991 Ph (772) 221-0653 Fax (772) 221-0102 http://www.paramount-seeds.com

Park Seed Co.

1 Parkton Avenue Greenwood, SC 29647 Ph (800) 213-0076 http://www.parkseed.com

Penn State Seed Co.

Box 390, Route 309 Dallas, PA 18612-9781 Ph (800) 847-7333 Fax (570) 675-6562 http://www.pennstateseed.com

Pepper Gal

P.O. Box 23006 Ft. Lauderdale, FL 33307-3007 Ph (954) 537-5540 Fax (954) 566-2208 http://www.peppergal.com

Pinetree Garden Seeds

P.O. Box 300 New Gloucester, ME 04260 Ph (207) 926-3400 Fax (888) 527-3337 http://www.superseeds.com

Redwood City Seed Co.

P.O. Box 361 Redwood City, CA 94064 Ph (650) 325-7333 Fax (650) 325-4056 http://www.ecoseeds.com

Renee's Garden Seeds

7389 W. Zayante Road Felton, CA 95018 Ph (888) 880-7228 Fax (831) 335-7227 http://www.reneesgarden.com

Rijk Zwaan

2274 Portola Drive Salinas, CA 93908 Ph (831) 484-9486 Fax (831) 484-9486 http://www.rijkzwaan.com

Rupp Seeds, Inc.

17919 County Road B Wauseon, OH 43567 Ph (419) 337-1841 Fax (419) 337-5491 http://www.ruppseeds.com

Rispens Seeds, Inc.

P.O. Box 310 Beecher, IL 60401 Ph (888) 874-0241 Fax (708) 746-6115 http://www.rispenseeds.com

Sakata Seed America, Inc.

P.O. Box 880 Morgan Hill, CA 95038-0880 Ph (408) 778-7758 Fax (408) 778-7751 http://www.sakata.com

Seeds of Change

621 Old Santa Fe Trail #10 Santa Fe, NM 87501 Ph (5888 762-7333 Fax (505) 438-7052 http://www.seedsofchange.com

Seedway, Inc.

1225 Zeager Road Elizabethtown, PA 17022 Ph (800) 952-7333 Fax (800) 645-2574 http://www.seedway.com

Seminis Inc.

2700 Camino del Sol Oxnard, CA 93030-7967 Ph (805) 647-1572 http://www.seminis.com

Shamrock Seed Co.

3 Harris Place Salinas, CA 93901-4856 Ph (831) 771-1500 Fax (831) 771-1517 http://www.shamrockseed.com

R.H. Shumway

334 W. Stroud Street Randolph, WI 53956-1274 Ph (800) 342-9461 Fax (888) 437-2773 http://www.rhshumway.com

Siegers Seed Co.

13031 Reflections Drive Holland, MI 49424 Ph (616) 786-4999 Fax (616) 994-0333 http://www.siegers.com

Snow Seed Co.

12855 Rosehart Way Salinas, CA 93908 Ph (831) 758-9869 Fax (831) 757-4550 http://www.snowseedco.com

Southern Exposure Seed Exchange

P.O. Box 460 Mineral, VA 23117 Ph (540) 894-9480 Fax (540) 894-9481 http://www.southernexposure.com

Southwestern Seed Co.

P.O. Box 11449 Casa Grande, AZ 85230 Ph (520) 836-7595 Fax (520) 836-0117 http://www.southwesternseed.com

Stokes Seeds, Inc.

P.O. Box 548 Buffalo, NY 14240-0548 Ph (716) 695-6980 http://www.stokesseeds.com

Sugar Creek Seed, Inc.

P.O. Box 508 Hinton, OK 73047 Ph (405) 542-3920 Fax (405) 542-3921 http://www.sugarcreekseed.com

Sutter Seeds

P.O. Box 1357 Colusa, CA 95932 Ph (530) 458-2566 Fax (530) 458-2721 http://www.sutterseed.com

Syngenta Seeds, Inc.

Rogers Brand Vegetable Seeds P.O. Box 4188 Boise, ID 83711-4188 Ph (208) 322-7272 Fax (208) 378-6625 http://www.rogersadvantage.com

-T-

The Territorial Seed Co.

P.O. Box 158 Cottage Grove, OR 97424-0061 Ph (541) 942-9547 Fax (888) 657-3131 http://www.territorial-seed.com

Thompson & Morgan, Inc.

P.O. Box 1308 Jackson, NJ 08527-0308 Ph (800) 274-7333 Fax (888) 466-4769 http://www.wholesale.thompsonmorgan.com/us/

Tokita Seed Co., Ltd.

1069 Nakagawa Omiya-shi Saitama-ken 300-8532 Japan http://www.tokitaseed.co.jp

Tomato Grower's Supply Co.

P.O. Box 2237

Ft. Myers, FL 33902

Ph (888) 478-7333

http://www.tomatogrowers.com

Otis S. Twilley Seed Co., Inc.

121 Gary Road

Hodges, SC 29653

Fax (864) 227-5108 http://www.twilleyseed.com

-U-

United Genetics

800 Fairview Road Hollister, CA 95023 Ph (831) 636-4882 Fax (831) 636-4883

http://www.unitedgenetics.com

U S Seedless, LLC

P.O. Box 3006 Falls Church, VA 22043 Ph (703) 903-9190 Fax (703) 903-9456 http://www.usseedless.com

-V-

Vermont Bean Seed Co., Inc.

334 W. Stroud Street Randolph, WI 53956-1274 Ph (800) 349-1071 Fax (888) 500-7333 http://www.vermontbean.com

Vesey's Seeds Ltd.

P.O. Box 9000 Charlottetown, PEI Canada C1A 8K6

Ph (902) 368-7333

Fax (800) 686-0329

http://www.veseys.com

Victory Seed Co.

P.O. Box 192 Molalla, OR 97038

Ph & Fax (503) 829-3126

http://www.victoryseeds.com

Vilmorin Inc.

2551 N. Dragoon Tucson, AZ 85175 Ph (520) 884-0011

Fax (520) 884-5102

Fax (520) 884-5102

http://www.vilmorin.com

Virtual Seeds

92934 Coyote Drive Astoria, OR 97103 Ph (503) 458-0919 http://www.virtualseeds.com

-W-

West Coast Seeds

3925 Sixty-fourth Street Delta, BC Canada V4K 3N2 Ph (604) 952-8820 Fax (8770 482-8822

http://www.westcoastseeds.com

Willhite Seed Co.

Box 23

Poolville, TX 76487-0023

Ph (800) 828-1840

Fax (817) 599-5843

http://www.willhiteseed.com

Wyatt-Quarles Seed Co.

P.O. Box 739

Garner, NC 27529

Ph (919) 772-4243

http://www.wqseeds.com

-Y-

Arthur Yates & Co. Ltd.

P.O. Box. 6672 Silverwater BC NSW 1811

Australia

http://www.yates.com.au

-Z-

Zeraim Gedera

P.O. Box 103 Gedera 70750

Israel

http://www.zeraimgedera.com

Information in this section was correct at the time of preparation. However, there are frequent changes in phone area codes, postal codes, addresses, and even company names. Suggest using your computer search engine if there is difficulty locating a specific concern.

PART 10

- 01 SOURCES OF VEGETABLE INFORMATION
- 02 PERIODICALS FOR VEGETABLE GROWERS
- 03 U.S. UNITS OF MEASUREMENT
- 04 CONVERSION FACTORS FOR U.S. UNITS
- 05 METRIC UNITS OF MEASUREMENT
- 06 CONVERSION FACTORS FOR SI AND NON SI UNITS
- 07 CONVERSIONS FOR RATES OF APPLICATION
- 08 WATER AND SOIL SOLUTION CONVERSION FACTORS
- 09 HEAT AND ENERGY EQUIVALENTS AND DEFINITIONS

01 SOURCES OF INFORMATION ON VEGETABLES

The Agricultural Experiment Station and Cooperative Extension Service in each state has been the principal source of information on vegetables in printed form. Most of this information is now on the Internet because of the high cost of producing, storing, and distributing printed information.

Websites providing information on vegetables from the state agricultural university in most states are listed below. If you are unable to access a site, try using the search engine on your computer.

| State | Website | Address/URL |
|-------------|--|---|
| Alabama | Commercial Vegetable Production | http://www.aces.edu/dept/com_veg |
| Arizona | Vegetables | http://cals.arizona.edu/crops/ vegetables/vegetables.html |
| Arkansas | Vegetables | http://aragriculture.org/horticulture/vegetables/default.asp |
| California | Vegetable & Research Information Center | http://vric.ucdavis.edu |
| | Vegetable Crops | http://www.anrcatalog.ucdavis.edu/ InOrder/Shop/Shop.asp |
| | Postharvest Technology | http://postharvest.ucdavis.edu. |
| Colorado | Specialty Crops Program | http://www.specialtycrops. colostate.edu/SCP_about.htm |
| Connecticut | Vegetables | http://137.99.85.230/FMPro |
| | Agricultural Experiment Station | http://www.caes.state.ct.us/ Publications/publications.htm |
| Delaware | Vegetable Program | http://www.rec.udel.edu/veggie/ veggie2001.htm |

| State | Website | Address/URL |
|---------------------------|---|---|
| Florida | Vegetable Crops | http://edis.ifas.ufl.edu/TOPIC_ Vegetables |
| | Watermelons | http://watermelons.ifas.ufl.edu |
| Georgia | Vegetables | http://www.uga.edu/~hort/ comveg.htm |
| Hawaii | Vegetables | http://www.ctahr.hawaii.edu/fb/ vege.htm |
| Illinois | Commercial Vegetable Production | http://www.nres.uiuc.edu/outreach/ pubs.html |
| Indiana | Purdue Fruit and Vegetable Connection | http://www.hort.purdue.edu/ fruitveg/vegmain.shtml |
| Iowa | Commercial Vegetables | http://www.public.iastate.edu/ ~taber/Extension/extension.html |
| Kansas | Horticulture Library | http://www.oznet.ksu.edu/library/ hort2 |
| Kentucky | Vegetable Information | http://www.uky.edu/Ag/ Horticulture/comveggie.html |
| Louisiana | Commercial Vegetable Production Recommendations | http://www. louisianalawnandgarden.org/en/ crops_livestock/crops/vegetables/ |
| Maryland | Crops, Livestock & Nursery | http://www.agnr.umd.edu/MCE/ Publications/Category.cfm?ID=C |
| Massachusetts Michigan | Vegetable Program Michigan Vegetable Information Network | http://www.umassvegetable.org http://web4.msue.msu.edu/veginfo/ index.cfm?doIntro=1 |
| Minnesota | Fruits and Vegetables | http://horticulture.coafes.umn.edu/ http://horticulture_coafes_umn_ edu_fruitveg.html |
| Mississippi | Commercial Horticulture | http://msucares.com/crops/comhort/index.html |
| Missouri | Horticulture Publications | http://muextension.missouri.edu/ explore/agguides/hort |
| Nebraska | Horticulture | http://ianrpubs.unl.edu/horticulture |

| State | Website | Address/URL |
|------------------|--|---|
| New Hampshire | Cooperative Extension's Vegetable Program | http://www.ceinfo.unh.edu/Agric/ AGFVC/FVCVEG.htm |
| New Jersey | Vegetable and Herb Crops | http://www.rcre.rutgers.edu/pubs/ subcategory.asp?cat=3⊂=24 |
| New York | Commercial Fruits and Vegetables | http://www.hort.cornell.edu/ extension/commercial/ comfryeg.html |
| | Vegetable Research and Extension | http://www.hort.cornell.edu/ department/faculty/rangarajan/ Veggie/index.html |
| North Carolina | Vegetable Crops | http://www.cals.ncsu.edu/hort_sci/veg/vegmain.html |
| Ohio | Vegetable Crops | http://extension.osu.edu/crops_and. livestock/vegetable_crops.php |
| | The Extension Vegetable Lab | http://www.oardc.ohio-state.edu/ Kleinhenz/Stuff/tm-wrkgrp1.htm |
| Oklahoma | Vegetable Trial Report | http://www.okstate.edu/ag/asnr/ hortla/vegtrial/index.htm |
| Oregon | Vegetable Production Guides | http://oregonstate.edu/Dept/ NWREC/vegindex.html |
| Pennsylvania | Vegetable Crop Resources | http://hortweb.cas.psu.edu/ extension/vegcrp.html |
| South Carolina | Vegetable & Fruit Program | http://virtual.clemson.edu/groups/ hort/vegprog.htm |
| Tennessee | Field and Commercial Crops | http://www.utextension.utk.edu/ publications/fieldCrops/ default.asp |
| Texas | Vegetable Web Sites Vegetable IPM | http://aggie-horticulture.tamu.edu/ extension/infolinks.html http://vegipm.tamu.edu |
| Vermont | Vermont Vegetable and Berry Page | http://www.uvm.edu/vtvegandberry |
| Virginia | Vegetable- Commercial Production | http://www.ext.vt.edu/cgi-bin/ WebObjects/Docs.woa/wa/ getcat?cat=ir-fv-vegc |

| State | Website | Address/URL |
|-------------------|--|---|
| Washington | Vegetable Research and Extension | http://agsyst.wsu.edu/vegtble.htm |
| | Vegetables | http://cecommerce.uwex.edu/ showcat.asp?id=18 |
| Ontario Canada | Vegetable Production Information | http://www.gov.on.ca/omafra/ english/crops/hort/vegetable.html |

SOME PERIODICALS FOR VEGETABLE GROWERS

American Fruit Grower American Vegetable Grower Florida Grower Greenhouse Grower Productores de Hortalizas Meister Media Worldwide 3377 Euclid Avenue Willoughby, OH 44094-5992 Ph (440) 942-2000 http://www.meistermedia.com

Carrot Country

http://www.columbiapublications.com/carrotcountry

Onion World

http://www.columbiapublications.com/onionworld

Potato Country

http://www.columbiapublications.com/potatocountry

The Tomato Magazine

http://www.columbiapublications.com/tomatomagazine Columbia Publishing 413-B N. Twentieth Avenue Yakima, WA 98902

Citrus & Vegetable Magazine

Subscription Service Center P.O. Box 83 Tifton, GA 31793 http://www.citrusandvegetable.com

The Grower

Subscription Service Center 400 Knightsbridge Parkway Lincolnshire, IL 60069-3613 Fax (847) 634-4373 http://www.growermagazine.com

The Packer

Circulation Department P.O. Box 2939 Shawnee Mission, KS 66201-1339 Ph (800) 621-2845 Fax (913) 438-0657 http://www.thepacker.com

The Produce News

482 Hudson Terrace Englewood Cliffs, NJ 07632 Ph (800) 753-9110 http://www.producenews.com

Western Grower and Shipper Magazine

P.O. Box 2130 Newport Beach, CA 92614 http://www.wga.com

Vegetable Growers News

http://www.vegetablegrowersnews.com

Spudman

http://www.spudman.com

Fresh Cut

http://www.freshcut.com

Fruit Grower News

http://www.fruitgrowersnews.com

Great American Publishing

P.O. Box 128 Sparta, MI 49345 Ph (616) 887-9008 Fax (616) 887-2666

Growing for Market

P.O. Box 3747 Lawrence, KS 66046 Ph (785) 748-0605 Fax (785) 748-0609

http://www.growingformarket.com

Potato Grower Magazine

http://www.potatogrowers.com

03 U.S. UNITS OF MEASUREMENT

Length

1 foot = 12 inches

1 yard = 3 feet

1 vard = 36 inches

1 rod = 16.5 feet

1 mile = 5280 feet

Area

1 acre = 43,560 square feet

1 section = 640 acres

1 section = 1 square mile

Volume

1 liquid pint = 16 liquid ounces

1 liquid quart = 2 liquid pints

1 liquid quart = 32 liquid ounces

1 gallon = 8 liquid pints

1 gallon = 4 liquid quarts

1 gallon = 128 liquid ounces

1 peck = 16 pints (dry)

1 peck = 8 quarts (dry)

1 bushel = 4 pecks

1 bushel = 64 pints (dry)

1 bushel = 32 quarts (dry)

Mass or Weight

1 pound = 16 ounces

1 hundredweight = 100 pounds

1 ton = 20 hundredweight

1 ton = 2000 pounds

1 unit (fertilizer) = 1% ton = 20 pounds

CONVERSION FACTORS FOR U.S. UNITS

| Multiply | Ву | To Obtain |
|---------------|-------------|---------------|
| Length | | |
| feet | 12. | inches |
| feet | 0.33333 | yards |
| inches | 0.08333 | feet |
| inches | 0.02778 | yards |
| miles | 5,280. | feet |
| miles | 63,360. | inches |
| miles | 1,760. | yards |
| rods | 16.5 | feet |
| yards | 3. | feet |
| yards | 36. | inches |
| yards | 0.000568 | miles |
| Area | | |
| acres | 43,560. | square feet |
| acres | 160. | square rods |
| acres | 4,840. | square yards |
| square feet | 144. | square inches |
| square feet | 0.11111 | square yards |
| square inches | 0.00694 | square feet |
| square miles | 640. | acres |
| square miles | 27,878,400. | square feet |
| square miles | 3,097,600. | square yards |
| square yards | 0.0002066 | acres |
| square yards | 9. | square feet |
| square yards | 1,296. | square inches |
| Volume | | |
| bushels | 2,150.42 | cubic inches |
| bushels | 4. | pecks |

| Multiply | Ву | To Obtain |
|-----------------|----------|-----------------|
| bushels | 64. | pints |
| bushels | 32. | quarts |
| cubic feet | 1,728. | cubic inches |
| cubic feet | 0.03704 | cubic yards |
| cubic feet | 7.4805 | gallons |
| cubic feet | 59.84 | pints (liquid) |
| cubic feet | 29.92 | quarts (liquid) |
| cubic yards | 27. | cubic feet |
| cubic yards | 46,656. | cubic inches |
| cubic yards | 202. | gallons |
| cubic yards | 1,616. | pints (liquid) |
| cubic yards | 807.9 | quarts (liquid) |
| gallons | 0.1337 | cubic feet |
| gallons | 231. | cubic inches |
| gallons | 128. | ounces (liquid) |
| gallons | 8. | pints (liquid) |
| gallons | 4. | quarts (liquid) |
| gallons water | 8.3453 | pounds water |
| pecks | 0.25 | bushels |
| pecks | 537.605 | cubic inches |
| pecks | 16. | pints (dry) |
| pecks | 8. | quarts (dry) |
| pints (dry) | 0.015625 | bushels |
| pints (dry) | 33.6003 | cubic inches |
| pints (dry) | 0.0625 | pecks |
| pints (dry) | 0.5 | quarts (dry) |
| pints (liquid) | 28.875 | cubic inches |
| pints (liquid) | 0.125 | gallons |
| pints (liquid) | 16. | ounces (liquid) |
| pints (liquid) | 0.5 | quarts (liquid) |
| quarts (dry) | 0.03125 | bushels |
| quarts (dry) | 67.20 | cubic inches |
| quarts (dry) | 2. | pints (dry) |
| quarts (liquid) | 57.75 | cubic inches |
| quarts (liquid) | 0.25 | gallons |
| quarts (liquid) | 32. | ounces (liquid) |
| quarts (liquid) | 2. | pints (liquid) |

| Multiply | Ву | To Obtain |
|-----------------|-----------|-----------------|
| Mass or Weight | | |
| ounces (dry) | 0.0625 | pounds |
| ounces (liquid) | 1.805 | cubic inches |
| ounces (liquid) | 0.0078125 | gallons |
| ounces (liquid) | 0.0625 | pints (liquid) |
| ounces (liquid) | 0.03125 | quarts (liquid) |
| pounds | 16. | ounces |
| pounds | 0.0005 | tons |
| pounds of water | 0.01602 | cubic feet |
| pounds of water | 27.68 | cubic inches |
| pounds of water | 0.1198 | gallons |
| tons | 32,000. | ounces |
| tons | 20. | hundredweight |
| tons | 2,000. | pounds |
| Rate | | |
| feet per minute | 0.01667 | feet per second |
| feet per minute | 0.01136 | miles per hour |
| miles per hour | 88. | feet per minute |
| miles per hour | 1.467 | feet per minute |

$\begin{array}{c} 05 \\ \text{METRIC UNITS OF MEASUREMENT} \end{array}$

Length

1 millimeter = 1,000 microns 1 centimeter = 10 millimeters 1 meter = 100 centimeters 1 meter = 1,000 millimeters 1 kilometer = 1,000 meters

Area

1 hectare = 10,000 square meters

Volume

1 liter = 1,000 milliliters

Mass or Weight

1 gram = 1,000 milligrams 1 kilogram = 1,000 grams 1 quintal = 100 kilograms 1 metric ton = 1,000 kilograms 1 metric ton = 10 quintals

CONVERSION FACTORS FOR SI AND NON-SI UNITS

| To Convert Column 1 into Column 2, Multiply by | Column 1 SI Unit | Column 2 non-SI Unit | To Convert Column 2 into Column 1, Multiply by |
|--|---|-------------------------------|--|
| Length | | | |
| 0.621 | kilometer, km (10^3 m) | mile, mi | 1.609 |
| 1.094 3.28 | meter, m meter, m | yard, yd foot, ft | $0.914 \\ 0.304$ |
| $1.0\\3.94\times10^{-2}$ | micrometer, μ (10 ⁻⁶ m) millimeter, mm (10 ⁻³ m) | micron, μ inch. in | 1.0 |
| 10 | nanometer, nm (10^{-9} m) | Angstrom, Å | 0.1 |
| Area | | | |
| 2.47 | hectare, ha | acre | 0.405 |
| 247 | square kilometer, $\mathrm{km^2}~(10^3~\mathrm{m})^2$ | acre | 4.05×10^{-3} |
| 0.386 | square kilometer, $\mathrm{km^2}~(10^3~\mathrm{m})^2$ | square mile, m^2 | 2.590 |
| 2.47×10^{-4} | square meter, $m^2 (10^3 m)^2$ | acre | 4.05×10^3 |
| 10.76 | square meter, $m^2 (10^3 m)^2$ | square foot, ft^2 | $9.29	imes10^{-2}$ |
| 1.55×10^{-3} | square millimeter, $m^2 (10^{-6} m)^2$ | square inch, in 2 | 645 |
| Volume | | | |
| $6.10 \times 10^4 \\ 2.84 \times 10^{-2}$ | cubic meter, m^3 liter, $L (10^{-3} m^3)$ | cubic inch, in³ bushel, bu | $\frac{1.64\times 10^{-5}}{35.24}$ |

| 0.946 28.3 3.78 2.96×10^{-2} 0.473 0.946 102.8 | $454 \\ 28.4 \\ 0.454 \\ 10^{2} \\ 907 \\ 0.907$ | 1.12 12.87 67.19 62.71 53.75 9.35 1.12×10^{-3} 2.24 0.477 |
|---|--|--|
| quart (liquid), qt cubic foot, ft ³ gallon ounce (fluid), oz pint (fluid), pt quart (liquid), qt acre-inch cubic foot, ft ³ | pound, lb ounce (avdp), oz pound, lb quintal (metric), q ton (2,000 lb), ton ton (U.S.), ton | pound per acre, lb acre ⁻¹ pound per bushel, lb bu ⁻¹ bushel per acre, 60 lb bushel per acre, 56 lb bushel per acre, 48 lb gallon per acre pound per acre, 10 acre ⁻¹ ton (2,000 lb) per acre, ton acre ⁻¹ |
| liter, L (10 ⁻³ m ³) meter ³ , m ³ meter ³ , m ³ | gram, g (10 ⁻³ kg) gram, g kilogram, kg kilogram, kg kilogram, kg megagram, Mg (tonne) | kilogram per hectare, kg ha ⁻¹ kilogram per cubic meter, kg m ⁻³ kilogram per hectare, kg ha ⁻¹ kilogram per hectare, kg ha ⁻¹ kilogram per hectare, kg ha ⁻¹ liter per hectare, L ha ⁻¹ megagram per hectare, Mg ha ⁻¹ megagram per hectare, Mg ha ⁻¹ megagram per hectare, Mg ha ⁻¹ |
| 1.057 3.53×10^{-2} 0.265 33.78 2.11 1.06 9.73×10^{-3} 35.7 | $Mass$ 2.20×10^{-3} 3.52×10^{-2} 2.205 10^{2} 1.10×10^{-3} 1.102 | Yield and Rate 0.893 7.77 × 10 ⁻² 1.49 × 10 ⁻² 1.59 × 10 ⁻² 1.86 × 10 ⁻² 0.107 893 0.446 2.10 |

| To Convert Column 1 into Column 2, Multiply by | Column 1 SI Unit | Column 2 non-SI Unit | To Convert Column 2 into Column 1, Multiply by |
|---|--|---|--|
| Specific Surface | | | |
| 10 | square meter per kilogram, m^2 | square centimeter per gram, cm^2 | 0.1 |
| 10^3 | ${ m kg}^{-1}$ square meter per kilogram, ${ m m}^2$ ${ m kg}^{-1}$ | g^{-2} square millimeter per gram, mm ² g^{-1} | 10^{-3} |
| Pressure | | | |
| 9.90 10 1.00 | megapascal, MPa (10 ⁶ Pa) megapascal, MPa (10 ⁶ Pa) megagram per cubic meter, Mg | atmosphere bar gram per cubic centimeter, $g 	ext{ cm}^{-3}$ | 0.101 0.1 1.00 |
| $2.09 	imes 10^{-2} \ 1.45 	imes 10^{-4}$ | m ^{_,} pascal, Pa pascal, Pa | pound per square foot, lb ${ m ft}^{-2}$ pound per square inch, lb in $^{-2}$ | $47.9\\6.90\times10^3$ |
| $\it Temperature$ | | | |
| $1.00~(^{\circ}\text{K} - 273)$ $(9/5^{\circ}\text{C}) + 32$ | Kelvin, K Celsius, °C | Celsius, °C Fahrenheit, °F | $1.00 (^{\circ}\text{C} + 273)$ $^{5}\% (^{\circ}\text{F} - 32)$ |

Energy, Work, Quantity of Heat

| To Convert Column 2 into Column 1, Multiply by | 102.8 101.9 0.227 0.123 1.03×10^{-2} 12.33 | 1 1 1 1 |
|--|--|--|
| Column 2 non-SI Unit | acre-inches, acre-in cubic feet per second, ft³ s ⁻¹ U.S. gallons per minute, gal min ⁻¹ acre-feet, acre-ft acre-inches, acre-in acre-feet, acre-ft | Concentrations of kg ⁻¹ milliequivalents per 100 grams, meq $100 \mathrm{g}^{-1}$ percent, % Mg gram per cubic centimeter, g cm ⁻³ kg ⁻¹ parts per million, ppm |
| Column 1 SI Unit | cubic meter, m ³ cubic meter per hour, m ³ h ⁻¹ cubic meter per hour, m ³ h ⁻¹ hectare-meters, ha-m hectare-meters, ha-m hectare-centimeters, ha-cm | centimole per kilogram, cmol kg ⁻¹ (ion exchange capacity) gram per kilogram, g kg ⁻¹ megagram per cubic meter, Mg m ⁻³ milligram per kilogram, mg kg ⁻¹ |
| To Convert Column 1 into Column 2, Multiply by | Water Measurement 9.73×10^{-3} 9.81×10^{-3} 4.40 8.11 97.28 8.1×10^{-2} | 1 0.1 1 |

07 CONVERSIONS FOR RATES OF APPLICATION

- 1 ton per acre = 20.8 grams per square foot
- 1 ton per acre = 1 pound per 21.78 square feet
- 1 ton per acre furrow slice (6-inch depth) = 1 gram per 1,000 grams soil
- 1 gram per square foot = 96 pounds per acre
- 1 pound per acre = 0.0104 grams per square foot
- 1 pound per acre = 1.12 kilograms per hectare
- 100 pounds per acre = 0.2296 pounds per 100 square feet
- grams per square foot \times 96 = pounds per acre
- kilograms per 48 square feet = tons per acre
- pounds per square feet \times 21.78 = tons per acre

08

WATER AND SOIL SOLUTION—CONVERSION FACTORS

Concentration

- 1 decisiemens per meter (dS/m) = 1 millimho per centimeter (mmho/cm)
- 1 decisiemens per meter (dS/m) = approximately 640 milligrams per liter salt
- 1 part per million (ppm) = 1/1,000,000
- 1 percent = 0.01 or 1/100
- $1 \text{ ppm} \times 10,000 = 1 \text{ percent}$
- $ppm \times 0.00136 = tons per acre-foot of water$
- ppm = milligrams per liter
- $ppm = 17.12 \times grains per gallon$
- grains per gallon = $0.0584 \times ppm$
- ppm = $0.64 \times \text{micromhos}$ per centimeter (in range of 100–5,000 micromhos per centimeter)
- ppm = $640 \times \text{millimhos}$ per centimeter (in range of 0.1–5.0 millimhos per centimeter)
- ppm = grams per cubic meter
- mho = reciprocal ohm
- millimho = 1000 micromhos
- millimho = approximately 10 milliequivalents per liter (meq/liter)
- milliequivalents per liter = equivalents per million
- millimhos per centimeter = EC \times 10 3 (EC \times 1,000) at 25 $^{\circ}$ C (EC = electrical conductivity)
- micromhos per centimeter = $EC \times 10^6 (EC \times 1,000,000)$ at 25°C
- millimhos per centimeter = 0.1 siemens per meter
- millimhos per centimeter = $(EC \times 10^3)$ = decisiemens per meter (dS/m)
- 1,000 micromhos per centimeter = approximately 700 ppm
- 1,000 micromhos per centimeter = approximately 10 milliequivalents per liter
- 1,000 micromhos per centimeter = 1 ton of salt per acre-foot of water
- milliequivalents per liter = $0.01 \times (EC \times 10^6)$ (in range of 100-5,000 micromhos per centimeter)
- milliequivalents per liter = $10 \times (EC \times 10^3)$ (in range of 0.1–5.0 millimhos per centimeter)

Pressure and Head

- 1 atmosphere at sea level = 14.7 pounds per square inch
- 1 atmosphere at sea level = 29.9 inches of mercury
- 1 atmosphere at sea level = 33.9 feet of water

- 1 atmosphere = 0.101 megapascal (MPa)
- 1 bar = 0.10 megapascal (MPa)
- 1 foot of water = 0.8826 inch mercury
- 1 foot of water = 0.4335 pound per square inch
- 1 inch of mercury = 1.133 feet water
- 1 inch of mercury = 0.4912 pound per square inch
- 1 inch of water = 0.07355 inch mercury
- 1 inch of water = 0.03613 pound per square inch
- 1 pound per square inch = 2.307 feet water
- 1 pound per square inch = 2.036 inches mercury
- 1 pound per square foot = 47.9 pascals

Weight and Volume (U.S. Measurements)

- 1 acre-foot of soil = about 4,000,000 pounds
- 1 acre-foot of water = 43,560 cubic feet
- 1 acre-foot of water = 12 acre-inches
- 1 acre-foot of water = about 2,722,500 pounds
- 1 acre-foot of water = 325,851 gallons
- 1 cubic-foot of water = 7.4805 gallons
- 1 cubic foot of water at $59^{\circ}F = 62.37$ pounds
- 1 acre-inch of water = 27,154 gallons
- 1 gallon of water at $59^{\circ}F = 8.337$ pounds
- 1 gallon of water = 0.1337 cubic foot or 231 cubic inches

Flow (U.S. Measurements)

- 1 cubic foot per second = 448.8 gallons per minute
- 1 cubic foot per second = about 1 acre-inch per hour
- 1 cubic foot per second = 23.80 acre-inches per hour
- 1 cubic foot per second = 3600 cubic feet per hour
- 1 cubic foot per second = about $7\frac{1}{2}$ gallons per second
- 1 gallon per minute = 0.00223 cubic feet per second
- 1 gallon per minute = 0.053 acre-inch per 24 hours
- 1 gallon per minute = 1 acre-inch in $4\frac{1}{2}$ hours
- 1000 gallons per minute = 1 acre-inch in 27 minutes
- 1 acre-inch per 24 hours = 18.86 gallons per minute
- 1 acre-foot per 24 hours = 226.3 gallons per minute
- 1 acre-foot per 24 hours = 0.3259 million gallons per 24 hours

U.S.-Metric Equivalents

- 1 cubic meter = 35.314 cubic feet
- 1 cubic meter = 1.308 cubic yards

- 1 cubic meter = 1000 liters
- 1 liter = 0.0353 cubic feet
- 1 liter = 0.2642 U.S. gallon
- 1 liter = 0.2201 British or Imperial gallon
- 1 cubic centimeter = 0.061 cubic inch
- 1 cubic foot = 0.0283 cubic meter
- 1 cubic foot = 28.32 liters
- 1 cubic foot = 7.48 U.S. gallons
- 1 cubic foot = 6.23 British gallons
- 1 cubic inch = 16.39 cubic centimeters
- 1 cubic yard = 0.7645 cubic meter
- 1 U.S. gallon = 3.7854 liters
- 1 U.S. gallon = 0.833 British gallon
- 1 British gallon = 1.201 U.S. gallons
- 1 British gallon = 4.5436 liters
- 1 acre-foot = 43,560 cubic feet
- 1 acre-foot = 1,233.5 cubic meters
- 1 acre-inch = 3,630 cubic feet
- 1 acre-inch = 102.8 cubic meters
- 1 cubic meter per second = 35.314 cubic feet per second
- 1 cubic meter per hour = 0.278 liter per second
- 1 cubic meter per hour = 4.403 U.S. gallons per minute
- 1 cubic meter per hour = 3.668 British gallons per minute
- 1 liter per second = 0.0353 cubic feet per second
- 1 liter per second = 15.852 U.S. gallons per minute
- 1 liter per second = 13.206 British gallons per minute
- 1 liter per second = 3.6 cubic meters per hour
- 1 cubic foot per second = 0.0283 cubic meter per second
- 1 cubic foot per second = 28.32 liters per second
- 1 cubic foot per second = 448.8 U.S. gallons per minute
- 1 cubic foot per second = 373.8 British gallons per minute
- 1 cubic foot per second = 1 acre-inch per hour (approximately)
- 1 cubic foot per second = 2 acre-feet per day (approximately)
- 1 U.S. gallon per minute = 0.06309 liter per second
- 1 British gallon per minute = 0.07573 liter per second

Power and Energy

- 1 horsepower = 550 foot-pounds per second
- 1 horsepower = 33,000 foot-pounds per minute
- 1 horsepower = 0.7457 kilowatts
- 1 horsepower = 745.7 watts

- 1 horsepower-hour = 0.7457 kilowatt-hour
- 1 kilowatt = 1.341 horsepower
- 1 kilowatt-hour = 1.341 horsepower-hours
- 1 acre-foot of water lifted 1 foot = 1.372 horsepower-hours of work
- 1 acre-foot of water lifted 1 foot = 1.025 kilowatt-hours of work

09

HEAT AND ENERGY EQUIVALENTS AND DEFINITIONS

- 1 joule = 0.239 calorie
- 1 joule = Nm (m^2 kg s^{-2})

temperature of maximum density of water = 3.98° C (about 39° F)

- 1 British thermal unit (Btu) = heat needed to change 1 pound water at maximum density of $1^{\circ}F$
- 1 Btu = 1.05506 kilojoules (kJ)
- 1 Btu/lb = 2.326 kJ/kg
- 1 Btu per minute = 0.02356 horsepower
- 1 Btu per minute = 0.01757 kilowatts
- 1 Btu per minute = 17.57 watts
- 1 horsepower = 42.44 Btu per minute
- 1 horsepower-hour = 2547 Btu
- 1 kilowatt-hour = 3415 Btu
- 1 kilowatt = 56.92 Btu per minute
- 1 pound water at 32°F changed to solid ice requires removal of 144 Btu
- 1 pound ice in melting takes up to 144 Btu
- 1 ton ice in melting takes up to 288,000 Btu

USEFUL WEBSITES FOR UNITS AND CONVERSIONS

- Weights, Measures, and Conversion Factors for Agricultural Commodities and Their Products (USDA Agricultural Handbook 697, 1992), http://www.ers.usda.gov/publications/ah697
- Metric Conversions (2002), http://www.extension.iastate.edu/agdm/wholefarm/html/c6-80.html
- A Dictionary of Units—Part 1 (2004), http://www.projects.ex.ac.uk/trol/dictunit/dictunit1.htm
- A Dictionary of Units—Part 2 (2004), http://www.projects.ex.ac.uk/trol/dictunit/dictunit2.htm
- U.S. Metric Association (2005), http://lamar.colostate.edu/~hillger

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