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## Appendix

# Crop Growth Requirements

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The following table of growth requirements is for plant species commonly grown in enclosed environments and provides suggested conditions to simulate average growth in field environments and commercial facilities. These are general suggestions that will provide good growth; it should be recognized, however, that conditions may differ for specific cultivars and may differ in particular commercial production facilities to fulfill specific quality or other requirements. Detailed information on nutrient solutions, lighting system lamp types, growing media, etc., is contained in the previous chapters of this handbook.

## ENVIRONMENTAL CONDITIONS

### *MEDIA AND NUTRITION*

Plants usually will be grown in a soilless potting medium or liquid culture. Several commercially available mixtures provide suitable media for plant growth, as discussed in the previous chapters. When plants are grown in a soilless media or liquid culture, use of a complete nutrient solution (approximating half strength Hoagland) is recommended, with the nitrogen concentrations modified as indicated in the table. Nitrogen is emphasized because this is the principal nutrient that is altered for a particular species or at particular stages of growth. If a soil-containing medium is used, it is recommended that the plants be fertilized with a commercial water-soluble fertilizer such as 20-10-20. When nitrogen concentrations are modified with a commercial fertilizer, P and K concentrations will also be modified. Recommendations for pH

assume that a range of 5.5 to 6.5 is acceptable for most plants, and a pH of 4.5 to 5.5 is acceptable for crops requiring low pH.

### *LIGHT*

The recommended photosynthetic photon flux (PPF) is for the top of the canopy. When light is indicated to be 12-20 hours, there is no specific daylength requirement for this species. The use of the longer period will provide a greater amount of total lighting, and thus an intensity toward the lower end of the recommended PPF range can be utilized to achieve good growth. If a short photoperiod is recommended, it is necessary to provide an intensity toward the high side of the recommended PPF range. No recommendations are provided on light source because chamber configuration, plant species, and desired response can all affect lamp selection. Users are referred to specific chapters in the text for detailed lighting design considerations in controlled environments. Special light requirements for specific species are noted in the comments column of the table.

### *TEMPERATURE*

Recommendations are for air temperature at canopy height. The temperature for most plants can be set 2 °C above or below the indicated temperatures and still produce normal plants, although growth rates will be altered. A light/dark fluctuation is recommended, and is required when shown in bold letters; most plants, however, will develop normally with a constant temperature that is an average of the indicated light and dark temperatures. The temperature period required to break bud dormancy of woody spe-

cies is cultivar dependent; thus, a range of time is indicated.

### **RELATIVE HUMIDITY**

Control between 60 and 70% relative humidity is recommended for most crops and can be achieved readily in most controlled environment chambers. Exceptions are noted in the comments column.

## **STAGES OF CROP DEVELOPMENT**

The environmental conditions required for successful plant growth in controlled environments are often not the same throughout all stages of plant growth. For that reason, the table has been divided into four, somewhat arbitrary, stages of development: Propagation, Vegetative, Flower Initiation/Development, and Fruit/Seed Development. These categories may not be technically correct for all the plants described, but they should provide functional guidelines for maintaining a desired growth rate for the listed species.

*Propagation* is considered the period from planting to emergence of the first true leaf. En-

vironmental conditions for acclimation of tissue-culture transplants, seedlings, and rooting of cuttings are also included in this section when they are considered to be routine propagation methods.

*Vegetative* is the period when reproductive structures are not actively developing on the plant. This typically includes the period of rapid stem elongation and leaf expansion that precedes flower formation. For woody species, this period may include the period of stem and leaf growth that occurs when flower buds are present but dormant.

*Flower initiation/development* is the period from the initiation of flowers through shedding of pollen (anthesis), flower formation, pollination, and fertilization. However, for many perennial woody plants, initiation of flower buds occurs at a time separate from flower development. The recommended environment for breaking dormancy of the initiated flower buds of these woody species is indicated in the comments column at the right margin.

*Fruit/seed development* is the period following fertilization to maturity of the seed.

PLANT Common Name (Genus species Auth.)	Nut. <sup>z</sup>	pH <sup>y</sup>	Propagation			Vegetative			Flower Initiation/Dev.			Fruit/Seed Dev.			Comments
			Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	
African Violet <i>Saintpaulia ionantha</i> H. Wendl	M	N	V	12	23 / 23	L	12	23 / 23	L	12	23 / 23				Leaf-petiole cuttings.
Ageratum <i>Ageratum houstonianum</i> Mill.	M	N	M	12-20	25 / 20	M	12-20	25 / 20	M	12-20	25 / 20				
Alfalfa <i>Medicago sativa</i> L.	M	N	M	12-20	25 / 20	M	12-20	22 / 22	M	>16	25 / 25	M	>16	25 / 25	Little flowering if photoperiod <12; High requirement for K & Mg.
Alstroemeria (Peruvian Lily) <i>Alstroemeria sp.</i> L.	H	N	M	>12	25 / 20	M	>12	20 / 20	M	>12	<b>20 / 15</b>				Division of rhizomes. For continuous flowering, temp. must be < 13 C.
Annual Bluegrass <i>Poa annua</i> L.	L	N	M	12-20	23 / 23	M	12-20	20 / 20	M	12-20	20 / 20	M	12-20		
Apple <i>Malus domestica</i> Borkh.	M	N				H	12-20	25 / 20	H	12-20	25 / 20	H	12-20	25 / 20	Break bud dormancy: 2000 to 2500 hrs at 4 C
Arabidopsis <i>Arabidopsis thaliana</i> L. Heynh	M	N	L	8	24 / 24	L	8	20 / 20	L	16	20 / 20	L	>16	20 / 20	Light inhibits germination.
Avocado <i>Persea americana</i> Mill.	M	N				M	12-20	25 / 20	M	12-20	20 / 15	M	12-20	25 / 20	Water stress induces flowering.
Azalea <i>Rhododendron spp.</i>	M	L	L	>14	25 / 23	M	>14	<b>25 / 20</b>	M	10	<b>25 / 25</b>				5-cm cuttings, 2500 ppm IBA. 5C for six weeks required for flower development after initiation
Barley <i>Hordeum vulgare</i> L.	M	N	M	12	23 / 18	M	12	<b>23 / 18</b>	M	16-24	23 / 18	M	16-24	23 / 18	

<sup>z</sup> Nutrition

L = Low (50 ppm N)  
M = Medium (100 ppm N)  
H = High (200 ppm N)

<sup>y</sup> pH

N = Normal 5.5 - 6.5  
L = Low 4.5 - 5.5

<sup>x</sup> Light: Photosynthetic Photon Flux (PPF)

D = Dark No light  
V = Very Low 50 - 150  $\mu\text{mol m}^{-2}\text{s}^{-1}$   
L = Low 150 - 250  $\mu\text{mol m}^{-2}\text{s}^{-1}$   
M = Medium 250 - 450  $\mu\text{mol m}^{-2}\text{s}^{-1}$   
H = High 450 - 700  $\mu\text{mol m}^{-2}\text{s}^{-1}$

PLANT Common Name (Genus species Auth.)	Nut. <sup>z</sup>	pH <sup>y</sup>	Propagation			Vegetative			Flower Initiation/Dev.			Fruit/Seed Dev.			Comments
			Light <sup>x</sup>	Photo-period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo-period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo-period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo-period Hrs / Day	Temp. (°C) Lt / Dark	
Bean <i>Phaseolus vulgaris</i> L.	M	N	M	12-20	22 / 22	M	12-20	22 / 22	M	12-20	22 / 18	M	12-20	25 / 20	Low night temperature for pollination and fruit set.
Blueberry, Highbush <i>Vaccinium corymbosum</i> L.	M	L				H	14	25 / 20	H	12-20	20 / 15	H	12-20	20 / 13	Break bud dormancy: 800 to 2500 hrs at 7.5 C. Initiate flower buds: < 12 hr photo period in fall for 50 days.
Blueberry, Rabbit-eye <i>Vaccinium ashei</i> Reade	L	L	H	12-20	25 / 20	H	14	25 / 20	H	12-20	25 / 20	H	12-20	25 / 20	Break bud dormancy: 300 to 800 hrs at 7 C. Flower bud initiation: < 12 hr photo period for 50 days in late fall.
Bramble <i>Rubus</i> spp.	L	N				M	12-20	25 / 20	M	12-20	25 / 20	M	12	25 / 20	Break bud dormancy: 750 to 2000 hrs at 4 C.
Cabbage <i>Brassica oleraceae</i> var. <i>capitata</i> L.	M	N	M	12-20	25 / 25	M	12-14	20 / 15	H	12-14	8 / 8	M	12-20	20 / 15	
Cactus, Thanksgiving <i>Schlumbergera truncata</i> (Haw.) Moran	M	N	M	>14	23 / 23	M	>14	25 / 18	M	<12	20 / 18				Commonly termed Christmas cactus Single stem section cuttings.
Calceolaria (Pocketbook Plant) <i>Calceolaria herbeohybrida</i> Voss.	M	N	L	12	20 / 20	M	>18	20 / 15	M	<8 >18	20 / 15 20 / 15				Two pre-anthesis stages: 6 wks short day and cool; 4-5 wks long day.
Carnation <i>Dianthus caryophyllus</i> L.	H	N	L	>12	20 / 15	M	<12	20 / 15	M	>12	18 / 13				4 wks long day initiates buds.
Cherry <i>Prunus</i> spp.	M	N				H	12-20	25 / 20	H	12-20	25 / 20	H	12-20	25 / 20	Break bud dormancy: 750 to 2000 hrs at 4 C.
Chrysanthemum <i>Dendranthema grandiflorum</i> (Ramato) Kitam	H	N	L	16	23 / 23	M	16	25 / 18	M	10	25 / 15				5 cm cuttings with 2500 ppm IBA.

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			Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	
Cineraria <i>Senecio cruentus</i> (Masson ex. L'Her.) D.C.	M	N	M	12	20 / 20	M	12	20 / 20	M	>12	20 / 13				In post-anthesis stage, do not allow to wilt.
Citrus <i>Citrus spp.</i>	M	N	M	12-20	28 / 23	H	12-20	28 / 23	H	12-20	28 / 23	H	12-20	28 / 23	Water stress induces flowering.
Cocklebur <i>Xanthium strumarium</i> L.	M	N	M	16	25 / 25	M	16-20	25 / 20	M	8	25 / 20	M	8	25 / 20	
Corn <i>Zea mays</i> L.	H	N	M	14	28 / 23	M-H	12-20	28 / 23	M-H	12-14	28 / 23	H	14	28 / 23	
Cosmos <i>Cosmos bipinnatus</i> Cav.	L	N	M	16	23 / 23	M	16	25 / 20	M	8	25 / 20				
Cotton <i>Gossypium hirsutum</i> L.	M	N	M	12-20	28 / 28	M	12-20	28 / 28	M	12	30 / 25	M	12-20	30 / 25	Most cultivars will flower under any photoperiod. Some cultivars require short days for flower initiation.
Cucumber <i>Cucumis sativus</i> L.	M	N	M	12-20	25 / 25	M	16	25 / 25	M	12-20	25 / 25	M	12-20	25 / 25	
Cyclamen <i>Cyclamen pesicium</i> Mill.	M	N	D	0	16 / 16	M	12	20 / 20	M	12	20 / 20				High temp. inhibits germination. In post-anthesis stage; do not allow to wilt.
Easter Lily <i>Lilium longiflorum</i> Thunb. var. <i>eximium</i> (Courtois) Baker	H	N				M	12	20 / 20	M	12	20 / 20				Bulbs cooled at 5 C for 6 weeks induces flowering.
Fuchsia <i>Fuchsia X hybrida</i> Hort. ex Vilm.	M	N	L	<12	23 / 23	M	<12	20 / 20	M	16	20 / 20				5-cm cuttings with 2500 ppm IBA.

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Geranium <i>Pelargonium spp.</i>	M	N	M	12-20	25 / 20	M	12-20	25 / 20	M	12-20	25 / 20				
Gerbera (Transvaal Daisy) <i>Gerbera jamesonii</i> Bolus ex Hook f.	H	N	L	>12	25 / 20	M	>12	25 / 18	M	>12	25 / 18				Seeds should not dry out.
Gloxinia <i>Sinningia speciosa</i> (Lodd.) Hiern	M	N	L	>12	20 / 20	M	>12	25 / 20	M	>12	25 / 20				Seeds uncovered on top of media.
Grape <i>Vitis spp.</i>	M	N	H	12-20	25 / 20	H	12-20	25 / 20	H	12-20	25 / 20	M	12-20	25 / 20	Break bud dormancy:750 to 3000 hrs at 4 C.
Henbane <i>Hyocyanus niger</i> L.	L	N	M	8	25 / 25	M	8	23 / 23	M	16	23 / 20				
Hydrangea <i>Hydrangea macrophylla</i> (Thunb.) Ser.	M	L,N	M	>14	23 / 23	M	>14	25 / 18	M	<14	25 / 15				5-cm cuttings with 2500 ppm IBA. Blue: pH<5.5. Pink: pH>6.5. 5 C for 6 wks required for flower development after initiation
Kalanchoe <i>Kalanchoe blossfeldiana</i> Poelln.	H	N	M	>14	23 / 23	M	>14	23 / 20	M	10	23 / 120				Seed or 5-7 cm cuttings.
Lambsquarters <i>Chenopodium album</i> L.	M	N	M	>14	25 / 20	M	>14	25 / 20	M	<12	25 / 20	M	<12	25 / 20	
Lettuce <i>Lactuca sativa</i> L.	M	N	L-M	12-20	25 / 20	M	12-20	25 / 20	M	12-20	25 / 20	M	12-20	25 / 20	Tip burn at high light, and high RH. 17 mol m <sup>-2</sup> day <sup>-1</sup> of PPF suggested.
Liatris (Gayfeather) <i>Liatris spp.</i>	H	N	L	>12	23 / 23	M	>12 Forcing	25 / 15	M	>12	25 / 15				Seed or division of corms. 2 C for 5 wks before forcing period.

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Marigold <i>Tagetes erecta</i> L.	M	N	M	12-20	25 / 20	M	12-20	25 / 20	M	12-20	25 / 20				
Oats <i>Avena sativa</i> L.	M	N	M	12-20	25 / 20	M	12-20	25 / 20	M	16-24	25 / 20	M	12-20		
Olive <i>Olea europaea</i> L.	M	N				H	14	23 / 18	H	12-20	12 / 12	H	12-20	23 / 18	Flower bud initiation: 750 to 2500 hrs at 12 C during early spring.
Pea <i>Pisum sativum</i> L.	M	N	M	12-20	23 / 23	M	12-20	23 / 23	M	12-20	20 / 15	M	12-20	23 / 18	Desirable at anthesis to reduce maximum temperature to 22C.
Peach <i>Prunus persica</i> (L.) Batsch	M	N				H	12-20	25 / 20	H	12-20	25 / 20	H	12-20	25 / 20	Break bud dormancy: 250 to 2000 hrs at 4 C
Peanut <i>Arachis hypogaea</i> L.	M	N	D	N/A	25 / 25	M	12-20	25 / 25	>M	12-20	30 / 23	>M	12-20	30 / 23	Plants flower under most photoperiods. Short days may increase harvest index.
Pear <i>Pyrus communis</i> L.	M	N				H	12-20	25 / 20	H	12-20	25 / 20	H	12-20	25 / 20	Break bud dormancy: 750 to 2500 hrs at 4 C
Pepper <i>Capsicum annuum</i> (L.) var. annuum	M	N	M	12-20	25 / 20	M	12-20	25 / 20	M	12-20	25 / 20	M	12-20	25 / 20	
Perilla <i>Perilla frutescens</i> (L.) Britt	L	N	M	16	25 / 25	M	16	20 / 20	M	8	20 / 20	M	8	20 / 20	
Petunia <i>Petunia x hybrida</i> Vilm.	M	N	M	12-20	25 / 20	M	12-20	25 / 20	M	16-20	25 / 20				

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			Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	Light <sup>x</sup>	Photo- period Hrs / Day	Temp. (°C) Lt / Dark	
Pharbitis <i>Pharbitis Nil</i> (L.) Roth	L	N	L	16	25 / 25	M	16	25 / 25	M	8	30 / 30				
Pigweed <i>Amaranthus spp.</i>	M	N	M	>16	25 / 20	M	>16	25 / 20	M	8	25 / 20				
Poinsettia <i>Euphorbia pulcherrima</i> Willd. ex Klotzsch	H	N	L	>14	25 / 20	M	>14	25 / 20	M	10	25 / 18				5-cm cuttings with 2500 ppm IBA.
Potato, Sweet <i>Ipomea batatas</i> (L.) Lam.	M	N	M	12-20	25 / 25	L	<14	25 / 25	M	>14	25 / 25	M	>14	25 / 25	Requirements are for storage root formation Higher N levels favor vegetative growth; requires high K.
Potato, White <i>Solanum tuberosum</i> L.	M	N	M	12-20	23 / 18	M	12-20	23 / 18	M	12-20	23 / 18	M	12-20	23 / 18	Requirements are for tuberization. Long days with low PPF delays tuberization. pH<6.0.
Rice <i>Oryza sativa</i> L.	M	N	M	12-20	30 / 20	>M	12-20	30 / 20	>M	12-20	30 / 20	>M	12	30 / 20	Short day crop; critical daylength for flowering varies with cultivar.
Rose <i>Rosa mult. flora</i> Thunb.	H	N	L	12	23 / 23	M	12	23 / 18	M	12	23 / 18				5-cm cuttings with 2500 ppm IBA.
Ryegrass <i>Lolium multiflorum</i> Lam.	M	N	M	12-20	23 / 18	M	12-20	20 / 15	M	16	23 / 18				
Salvia <i>Salvia splendens</i> Sellow ex Schultes	L	N	M	24	23 / 23	M	12	25 / 20	M	12	25 / 20				
Scrophularia <i>Scrophularia marilandica</i> L.	L	N	L	8	20 / 13	M	8	20 / 20	M	16	20 / 20				

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Silene <i>Silene armeria</i> L.	L	N	D	N/A	25 / 25	M	8	20 / 20	M	16	20 / 20				
Sinapsis <i>Sinapsis alba</i> L.	L	N	M	12-20	25 / 25	M	12-20	20 / 20	M	8	20 / 20				
Snapdragon <i>Antirrhinum majus</i> L.	H	N	M	>12	23 / 23	M	>12	25 / 15	M	>12	20 / 13				Sow seed on top of moist media. Facultative long day for flowering.
Soybean <i>Glycine max</i> (L.) Merr	M	N	M	12	28 / 23	M	12-20	28 / 23	M	12-20	28 / 23	M	12	28 / 23	Short day crop; critical daylength for flowering varies with cultivar
Spinach <i>Spinacia oleracea</i> L.	M	N	M	12	20 / 20	M	12	20 / 20	M	>15	25 / 25	M	>15	25 / 25	Elevated temperatures encourage earlier flowering.
Strawberry <i>Fragaria x ananassa</i> Duch.	M	N	M	12-20	18 / 18	M	12-20	20 / 15	M	<12	20 / 15	M	12-20	20 / 15	For day neutral cultivars only: exposing crowns to 4-6 wks at 4 C will stimulate flowering.
Tobacco <i>Nicotiana tabacum</i> L.	M	N	M	12-20	25 / 20	M	12-20	25 / 20	M	12-20	25 / 20	M	12-20	25 / 20	
Tomato <i>Lycopersicon esculentum</i>	M	N	M	12-20	25 / 20	H	12-20	25 / 20	H	12-20	25 / 20	H	12-20	25 / 20	Requires high K and Ca. High nutrition may induce fruit set.
Wheat <i>Triticum aestivum</i> L.	M	N	M	12-20	25 / 20	M	12-20	20 / 15	M	12-20	23 / 18	H	12-20	23 / 18	Winter wheat requires cold treatment (vernalization) for floral induction. Long photoperiod decreases time to flowering.

<sup>z</sup> Nutrition  
L = Low (50 ppm N)  
M = Medium (100 ppm N)  
H = High (200 ppm N)

<sup>y</sup> pH  
N = Normal 5.5 - 6.5  
L = Low 4.5 - 5.5

<sup>x</sup> Light: Photosynthetic Photon Flux (PPF)  
D = Dark No light  
V = Very Low 50 - 150  $\mu\text{mol m}^{-2}\text{s}^{-1}$   
L = Low 150 - 250  $\mu\text{mol m}^{-2}\text{s}^{-1}$   
M = Medium 250 - 450  $\mu\text{mol m}^{-2}\text{s}^{-1}$   
H = High 450 - 700  $\mu\text{mol m}^{-2}\text{s}^{-1}$