Great Lakes Fruit, Vegetable & Farm Market EXPO
Michigan Greenhouse Growers EXPO

December 5-7, 2017

DeVos Place Convention Center, Grand Rapids, MI

The ABC's of Growing Plugs from Seed

Where: River Overlook (upper level) Room A & B

Join two propagation experts as they combine their technical experiences and research knowledge to help improve your success during plug production. You will gain a better understanding of the ins and outs of growing plugs from seed.

MI Recertification credits: 1 (COMM CORE, PRIV CORE)
Moderator: Roberto Lopez, Horticulture Dept., MSU

10:00 am — The ABC's of Growing Plugs from Seed

- Jamie Gibson, Syngenta Flowers, Home and Garden, Greensboro, N.C.
- Roberto Lopez, Horticulture Dept., MSU

10:50 am — Session Ends

Sponsored by Syngenta Flowers

Propagation of Herbaceous Plants: Principles and Methodology

James L. Gibson
Syngenta Flowers, Inc.

Where, why and how do bedding plant, pot crop, foliage, and perennial seedlings or cuttings originate? In order for plants to reproduce, the process of either sexual or asexual propagation needs to occur. These forms of regeneration or replication have been labeled as both an art and a science, and producers must learn both facets so that their product is successful. This handout covers the basic principles of annual and perennial production and can serve as a general reference for herbaceous propagation.

Annuals: Seed Propagation

Seeds are the product of sexual propagation and represent an entire embryonic plant that is covered by protective tissue. Seeds are considered dormant until they are exposed to favorable environmental factors such as moisture, warm temperatures, and light that encourage germination. There are many important factors that propagators must consider about seeds before germination.

Knowing the history of how most growers produced **seedlings** is the first lesson, and this ultimately affects what direction a grower will take in handling young plants. Traditionally, growers would "open sow" seeds in flats and achieve clumps or rows of seedlings. These seedlings would then be transplanted by hand into final containers. Not only did this method require a large amount of labor, but it results in slower growing plants which sometimes flowered later and were more susceptible to disease and poor cultural practices.

Plugs have become the chosen method for the production of young plants from seed. Basically, a plug is a seedling that is produced in its own individual container or cell. A plug tray contains many cells (72 to 800) and these trays are commercially produced by specialists. Plugs have many advantages: less labor inputs, faster growing times, less root shock and plant stress, and uniform growth of plants in the final container.

Growers interested in plug production must also consider the disadvantages: higher costs per seedling, greater space requirements during plug production, specialized equipment, techniques, and personnel. Growers that are new to the business may want to initially buy in plugs to become familiar with the quality, handling, and cost issues that surround this modern strategy in seedling production.

The issue of **seed quality** plays a major role in the success of a germinating seed. Growers should purchase seed from a reputable seed salesman, and all seed purchased should be labeled as certified with a seed lot number and germination percentage on the package. The large seed suppliers have their own testing labs for vigor and viability, and it is recommended that purchases be made with these firms.

Seeds should be stored at a temperature between 40 to 70°F, with a relative humidity between 20 to 40%. These ranges have been established so that seeds do not lose their vigor and viability. Most growers **store seeds** in a cool chamber such as a refrigerator that does not have a high relative humidity. Properly stored seeds should have a moisture content between 5 to 8%.

The type of **substrate** or medium used for germination is important to the establishment of the seedling. In general, a substrate should be light and porous to provide adequate oxygen, yet retain moisture and allow for proper drainage. Most commercial germination mixes contain a blend of peat moss, vermiculite, perlite, and sometimes sand. The germination mix should be free of weed seeds and pests (insects and disease organisms), low in nutrients, and have a pH between 5.4 to 6.4.

The **temperature of the propagation medium** should be high, and a general range for floricultural crops would be 68 to 86°F. Most seeds will germinate at 75°F, but one should always check the germination requirements of specific seed. Not only do specific species require an optimum germination temperature, but some seeds may or may not require light. There have been many published charts on the germination requirements of herbaceous plants that should not be difficult to acquire (Nau, 1999; Styer and Koranski, 1997). If seeds are to be covered, a general rule of thumb is to cover the seed with ¼ the length of the seed with a loose propagation substrate (coarse vermiculite or perlite is often used). Along with a light covering of mix or a mix component, some growers will cover the flats with white or black plastic to keep moisture levels high and prevent rapid drying of the germination substrate. The plastic is then removed after the seedling protrudes from the substrate surface.

After the seedling has developed its **first true leaves**, a mild fertilizer solution can be applied. Nitrogen concentrations of 50 to 75 ppm are recommended. Plugs are usually transplantable 3 to 6 weeks after sowing, and a general rule of thumb is when leaves begin to touch one another, the plants are ready to transplant.

Annuals: Vegetative Propagation

Asexual propagation is a process where a new plant is produced from plant parts: leaves, stems, buds, or roots. This form of replication produces plants or clones that are genetically identical to the mother plant, from where the plant part was taken. Asexual propagation of floricultural crops has become a means of producing plants which have been produced from seed for many years. Crops like coleus, impatiens, strawflower, and verbena fall into this category. Crops like poinsettias and chrysanthemums have traditionally been propagated vegetatively.

Knowing how the **vegetative propagation industry** has evolved is just as important as the principles behind vegetative propagation. The increasing use of vegetative cuttings for hanging baskets, color bowls, and pots has led to an integrated production and supply system today that involves plant breeders, stock plant managers, propagators, brokers, and growers.

Breeders are the first to develop a new plant line by conducting massive evaluation trials for selection of premium genetic material. After a plant has been selected for replication, its numbers are increased through stock plant or mother plant production. Offshore production of stock plants, mainly in Central America, has been the strategy in which to take advantage of ideal environmental conditions, shipping and labor costs.

Cuttings are harvested from these plants and are shipped to the U.S. to either rooting stations or grower locations. Propagation firms have established networks of specialized propagators who root cuttings and ship to clients either regionally or on the national level.

Because new lines of plants are being developed every year, most of the recently introduced **vegetatively propagated species are patented** or protected, where the average grower cannot replicate these plants for profit. Propagation firms charge royalty fees for patented material and some firms may charge more to growers who propagate unrooted material. Today the industry is carefully monitored for plant quality and business integrity, because the amount of investment for clean (virus and disease free) plants is very expensive.

How do the firms **ensure quality plant material**? One method is the technique called culture indexing. Plant viruses cannot keep up with the rapid growth in the shoot tips of plants, therefore scientists grow new plants from these shoot tips on sterile media, then culture test them over several months to ensure clean stock plant material. The technique is also used to eliminate bacteria or fungi from harboring in young plants. Other control measures include insect screening and attentive stock plant management.

The **propagation environment** for leaf or stem tip cuttings changes over time because the needs of the tissue change as it develops roots and becomes a functional plant. A good rule to remember for successful propagation of cuttings is the "warm bottoms", "misty middles", and "cool tops" principle.

Cuttings need warm bottoms for proper cell division and growth of newly forming adventitious roots. Propagators supply **bottom heat** to cuttings to accelerate rooting, with a preferred temperature range between 68 to 77°F. Bottom heat can be supplied in many ways. Common strategies for providing bottom heat include propagation mats which have electrically heated wires encased in rubber, heating tubes on benches which carry warm water, and steam pipes under benches. The air temperature also effects growth and should be maintained between 65 to 75°F.

Keeping the **humidity** high is important for propagating herbaceous plants. Newly "stuck" cuttings require a water source to remain turgid. Treating the cuttings with intermittent mist or fog keeps the substrate moist and prevents the cuttings from wilting. Monitoring root growth and development overtime and observing the ability of the cutting to remain turgid with less mist helps the propagator regulate the amount of water to the plant. If the water source is not regulated and the cuttings are continually rooting in saturated conditions, root growth and development will be slowed because of oxygen depletion in the substrate.

Light, in particular light level, has a tremendous effect on the success of rooting cuttings. Cuttings should be protected with shade cloth during parts of the year with high light levels and if light levels are too low in the winter, propagators should provide supplemental light. A general light level range for the propagation of floricultural crops is 1,000 to 2,000 footcandles.

Several **substrates** are used to root cuttings. Overall propagators want a substrate that retains moisture, but provides adequate oxygen and will support a cutting upright. Not only do propagators use perlite, vermiculite, and peat, but foam is used to root cuttings. A common type of foam product used is the Smithers-Oasis Root Cube or Wedge®.

In general, cuttings root 3 to 5 weeks within the propagation environment. Propagators remove cuttings from bottom heat after roots reach the bottom of the tray and typically apply a moderate amount of fertilizer (75 to 200 ppm nitrogen) to the cuttings because leaching of nutrients from the substrate and plant tissue has occurred. It is important to fertilize recently propagated material because this nutrient treatment affects the growth and development of the plant once placed in its final container.

Perennials

Perennials have become an important component of a greenhouse grower's production list. The nature of the plant has made gardeners appreciate its repeating lifecycle, and through its popularity has come an increased demand for production information. Perennial propagation involves a tremendous amount of skill and because there are thousands of species with specific germination requirements many growers purchase plugs from specialty propagators.

One of the most common means of propagating perennials is by **division**. Most mail order perennial suppliers propagate by division where large portions of land are donated to producing field-grown perennials. The plants are normally divided in the fall or early spring. Propagators who divide in the spring allow for 3 to 5 inches of growth from the crown of the plant and segment the plant with a sharp spade or serrated knife.

Because most perennials do not flower the first year, propagators sow seed during the summer months and transplant into larger containers in the late summer and early fall. This strategy is also conducted before winter because a large majority of perennials require a cold period or a **vernalization** treatment for spring or summer flowering. Even before germination is to occur some perennial seeds may require **special treatments** to break dormancy. Certain species of perennial seed require a period of moist chilling or warm stratification. Other types of seed may require a treatment known as scarification. Scarification involves breaking or weakening the seed coat for the penetration of oxygen and water to the embryo through chemical or physical means. Uniform germination is rarely achieved with perennials and it may be more economically feasible to root vegetative cuttings of perennials.

Vegetative propagation is a fairly new approach to replicating perennials, with a large amount of production information still unknown. Research is now focusing on manipulating the plants through increased daylength and temperature effects in order to condition the plants to flower. Propagation by tip cuttings allows for more uniform growth in the rooting tray and the plants are more true to type than seed propagated perennials. Successful propagation by cuttings can be achieved by following the same guidelines established with vegetative annuals.

Sanitation and Pest Control

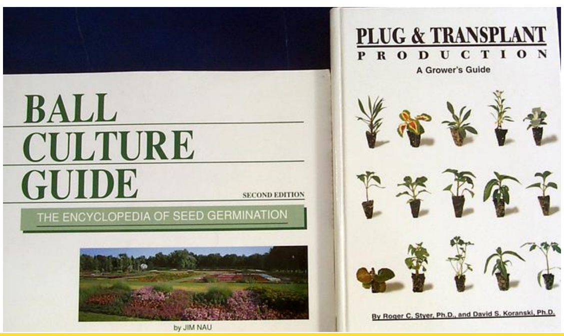
Because temperature and humidity are normally higher in propagation houses, the incidence of disease is greater. Diseases thrive in environments which allow for easy survival and transmittance of fungi and bacteria. Propagators should establish strict sanitation measures to prevent diseases so production is optimized and profits always exceed losses. All containers should be sterilized before reuse in the propagation area and workers should wash their hands thoroughly before handling unrooted material. It is recommended that a 10% Chlorox® solution in the propagation area at all times. Disinfectants labeled for greenhouses should be applied to benches, flats, pots, knives, walls, and floors before initiating any propagation activity. Not only are diseases economically devastating in propagation, but insects can cause loss of profits. Greenhouses should be monitored for pests routinely with yellow and blue sticky cards, while growers should periodically check vegetation for signs of insects or insect damage.

The ABC's of Growing Plugs from Seed

Technical Services
Syngenta Flowers, LLC

Commercial Plug Production

Resources for Seed Plugs



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Pros and Cons of Seed Plug Production

Advantages

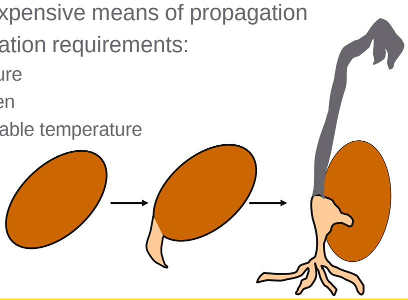
- Relatively simple to produce and use seeds
- Usually least expensive means of propagation
- Seeds are a convenient method of storing and handling plants
- Generally produce disease-free plants
- Generally produce plants “true to type”

Disadvantages

- Seed storage requirements may be specific for crop
  - short term < 2yr: 32-50 ºF, 50-65% RH
  - long term >2yr: 0-32 ºF, 4-6% RH
- Specific germination requirements for some crops

Sexual Propagation: Seeds

- Least expensive means of propagation
- Germination requirements:
  - Moisture
  - Oxygen
  - Favorable temperature



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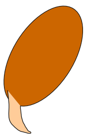

- Seed quality
  - Viability and vigor
- Seed treatments
  - Pelleted, primed and/or pre-germinated: To improve planting precision and seedling performance
  - Pelleted: small or irregular seed
  - Primed: pansy, verbena, vinca; expect more rapid deterioration of primed seed

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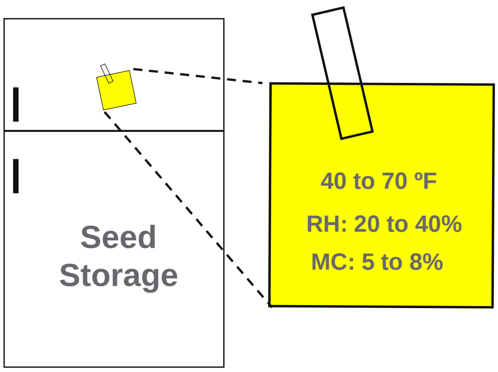
Poor germination due to insufficient water applied at time of sowing

Pelleted petunia seed may need extra water at the time of sowing to remove the pelleting material.

If the pelleting material does not dissolve quickly, it can result in poor, uneven germination



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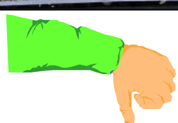
Disadvantages of Transplanting Seedlings

- Large labor input
- Slower growing plants
  - Root shock
  - Less uniformity
  - Later flowering
- Increased chances
  - Diseases
  - Insects



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Bedding Plant Plugs

- Growing plants from germination to transplant in flats of > 72 cells/tray
- Mechanization in seeding, growing, transplanting
- Time, space, labor optimized

Benefits of Plugs

- Single-cell plants more vigorous, have less disease, easier to handle
- Able to hold plugs longer in tray
- Less transplant shock
- Reduced cropping time which allows multiple crops per season
- Cheaper than seedlings

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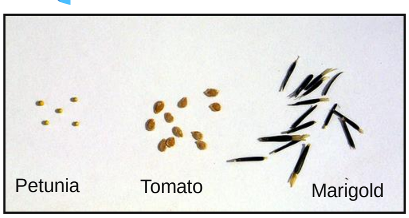
Seed Size and Depth of Planting

Rule of  : A covering depth of 1/4 the length of the seed



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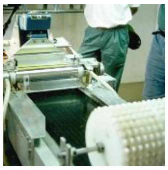
Seeders $$$: One to few seeds per cell

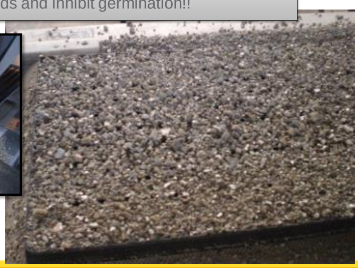


- A MUST for plugs
- Requires more seed than traditional sowing
- Should handle different size trays
- Must be adjustable for seed size and type

Culture Update for Pansy Production

Plug Production

Caution!
Covering plug trays too heavily with vermiculite can smother the seeds and inhibit germination!!



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Germination Chambers

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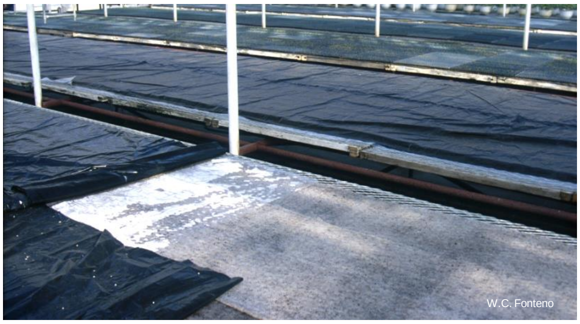
Germination in the Greenhouse



Poor Germination

- Seed quality
- Humidity
- Temperature
- Watering
- Compacted substrate
- Contaminated substrate

Always check the specific seed requirements for proper germination.

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Moistures stages are critical to success.

Water level	Description
1 DRY	Soil is tan to grey in color, trays are extremely light, soil pulls away from sides of container
2 MEDIUM	Soil is light brown in color, no water can be extracted from soil, soil will crumble apart
3 MOIST	Soil is brown in color, strongly squeezing the soil will extract a few drops of water, trays are light with no visible bend
4 WET	Soil is dark brown but NOT shiny, no free water is seen at the surface of the soil, when pressed or squeezed water drips easily, trays are heavy with a visible bend in the middle
5 SATURATED	Soil is dark brown and shiny, free water is present at the surface of the soil, water drips freely from bottom of tray, trays are heavy with a visible bend in the middle

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Double sown plugs

Multiple sown seedlings

Avoid Stacking Trays

- Stacked trays cause media compaction
- Compaction leads to non-uniform watering and growth

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Compaction Leads to Uneven Growth

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Media Compaction Reduces Growth

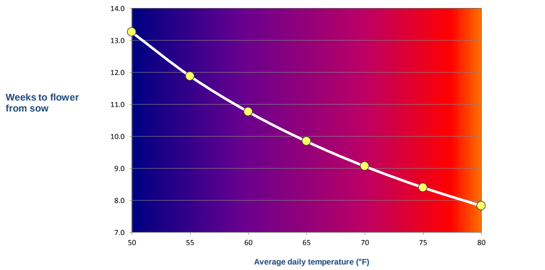
Good Soil Compacted

Good Soil Compacted

Delta™ Premium / Delta™ Pansy

Estimated Total Crop Time from Seed Sow

Photoperiod: 10 – 12 hours



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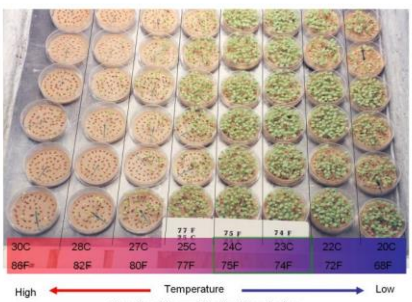
Pinto™ Premium Geranium Series

Germination



Geranium Thermo-Gradient Germination

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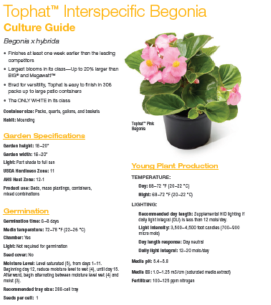
Young Plant Production



Tophat™ Interspecific Begonia
Culture Guide

Begonia x hybrida

- Finishes at least one week earlier than the leading competitors
- Largest blooms in its class—Up to 20% larger than BIG® and Megawatt™
- Bred for versitility, Tophat is easy to finish in 306 packs up to large patio containers
- The ONLY WHITE in its class

Container size: Packs, quarts, gallons, and baskets
Habit: Mounding

Garden Specifications

Garden height: 16–20"
Garden width: 16–20"
Light: Part shade to full sun
USDA Hardiness Zone: 11
AHS Heat Zone: 12-1
Product use: Beds, mass plantings, containers, mixed combinations

Germination

Germination time: 6–8 days
Media temperature: 72–78 °F (22–26 °C)
Chamber: Yes
Light: Not required for germination
Seed cover: No
Moisture Level: Level saturated (5), from days 1–11. Beginning day 12, reduce moisture level to wet (4), until day 15. Afterward, begin alternating between moisture level wet (4) and moist (3).
Recommended tray size: 288-cell tray
Seeds per cell: 1

Tophat™ Pink Begonia

Young Plant Production

TEMPERATURE:
Day: 68–72 °F (20–22 °C)
Night: 68–72 °F (20–22 °C)

LIGHTING:
Recommended day length: Supplemental HID lighting if daily light integral (DLI) is less than 12 mols/day.
Light intensity: 3,500–4,500 foot candles (700–900 micro mols)
Day length response: Day neutral
Daily light integral: 12–20 mols/day

Media pH: 5.4–5.8
Media EC: 1.0–1.25 mS/cm (saturated media extract)
Fertilizer: 100–125 ppm nitrogen

Temperature:
Day: 68–72 °F (20–22 °C)
Night: 68–72 °F (20–22 °C)

Lighting:
Recommended day length: Supplemental HID lighting if daily light integral (DLI) is less than 12 mols/day.
Light intensity: 3,500–4,500 foot candles (700–900 micro mols)
Day length response: Day neutral
Daily light integral: 12–20 mols/day

Media pH: 5.4–5.8

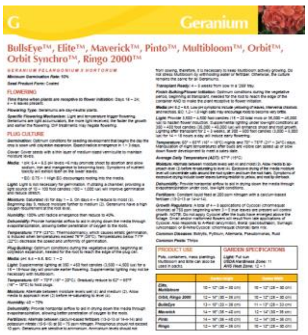
Media EC:
1.0–1.25 mS/cm (saturated media extract)

Fertilizer: 100–125 ppm nitrogen

Pinto™ Premium Geranium Series
Plug Production

Plug Scheduling

Tray size	Weeks
105	6 – 7
128	5 – 6
288	4 – 5
512	3 – 4



G Geranium

BullsEye™, Elite™, Maverick™, Pinto™, Multibloom™, Orbit™, Orbit Synchro™, Ringo 2000™

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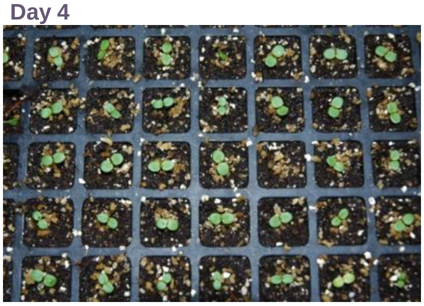
Pinto™ Premium Geranium Series
Plug Production

Day 4



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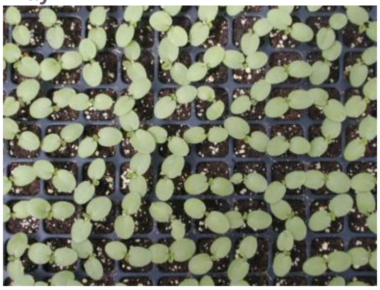
Pinto™ Premium Geranium Series
Plug Production

Day 12



Pinto™ Premium Geranium Series
Plug Production

Day 15

Day 18

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Culture Update for Pansy Production
Plug Production

Avoid keeping soil media too wet during plug stage 2!

Pansies will exhibit "root running" when soil *moisture* *<u>is too high during stage 2</u>* of plug growth

Pansies commonly have this problem when trays are kept too wet at this stage, especially during fall pansy plug production

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Maintaining proper pH and electrical conductivity will prevent most nutritional problems.

Maintaining proper media pH during holding is **CRITICAL**!

- Monitor pH of plugs on a weekly basis
- Use fertilizer formulations that will keep pH in the targeted range depending on species

Species sensitive to pH HIGHER THAN 6.5	Species sensitive to pH LESS THAN 6.0
Dianthus	Lisianthus
Gerbera	New Guinea Impatiens
Pansy	Marigold
Petunia	Seed Geraniums
Primula	Pentas
Snapdragon	
Verbena	
Vinca	

Culture Update for Pansy Production

Plug Production

Fertilizer

- Use calcium nitrate based fertilizers (e.g., 13-2-13, 15-5-15) for plug production
- Avoid fertilizers high in phosphorus to prevent stretch
- Maintain a boron concentration of 0.5 ppm in the media

Fungicide

- Apply a preventative Medallion® fungicide drench for Thielaviopsis especially if growing at cool temperatures

4 weeks after sow

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Plug Production - Fertilization

Use Fertilizers that are:

High in NO_3 & K_2O

Low in P_2O_5 & NH_4

Nitrate nitrogen and Potassium will keep plants toned and green

Restricting Phosphorus and Ammonium Nitrate will help hold size until transplanting

RECOMMENDED FERTILIZERS FOR HOLDING PLUGS
13-2-13 (8% NH_4 – N) – basic
15-0-15* (10% NH_4 – N) – basic
15-2-20 (15% NH_4 – N) - neutral
17-5-17 (25% NH4 – N) – neutral

Apply recommended fertilizers at 50 – 75 ppm Nitrogen constant feed, with one clear water application per week

**Use 15-0-15 as part of a rotation to avoid phosphorus deficiency*

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Plug Production

Avoid using fertilizers with high levels of phosphorus during plug production to prevent stretch!

Growers need to have a PGR toolbox.

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Culture Update for Pansy Production
Plug Production

Plant Growth Regulator Recommendations:

- Spray B-Nine® at 1,500 – 2,500 ppm once cotyledons have fully expanded
- Spray B-Nine at 2,500 – 3,500 ppm or A-Rest® plant growth regulator at 3 - 6 ppm once first set of leaves has expanded
- Spray a tank mix of B-Nine at 2,500 ppm + A-Rest at 3 ppm to hold

Increased concentrations may be necessary if temperatures exceed 75 °F

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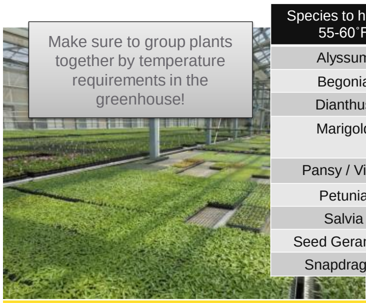
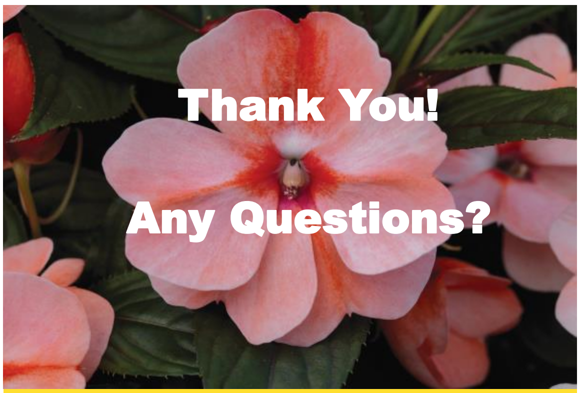
HOLDING PLUGS PAST TRANSPLANT DATES

TEMPERATURES & LIGHT LEVELS



Species to hold at 55-60˚F	Species to hold above 60˚F
Alyssum	Ageratum
Begonia	Celosia
Dianthus	Coleus
Marigold	Impatiens / New Guinea Impatiens
Pansy / Viola	Pentas
Petunia	Portulaca
Salvia	Verbena
Seed Geranium	Vinca
Snapdragon	Zinnia



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Part 1 of a four-part series on manipulating light quality, quantity, duration and carbon dioxide during plug production.

Producing High-Quality Plugs

How light quality, light quantity and carbon dioxide influence young plant production in greenhouses and indoor controlled environments.

Allison Hurt & Roberto Lopez

Every grower has their own protocol or recipe for producing plugs and rooted cuttings that works best with their growing environment, resources and needs. However, there's always room for improvement.

In this four-part series, we'll highlight our most recent greenhouse photoperiodic and supplemental lighting research utilizing light-emitting diodes (LEDs) during the production of both plugs and liners. Lastly, we'll introduce you to the exciting possibilities that exist with indoor vertical production of young plants utilizing sole-source LED lighting and carbon dioxide (CO_2) injection.

Over the last decade, our research has quantified the influence of light quantity and quality during young plant production on numerous ornamental species. Our general recommendation for most young plants is to provide 70 to 90 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ of supplemental light to achieve a target daily light integral (DLI) of 10 to 12 $mol{\cdot}m^{-2}{\cdot}d^{-1}$. As a result, many growers are now producing young plants under supplemental lighting from high-pressure sodium (HPS) lamps, while others have made the investment in high-intensity LED fixtures (Figure 1A-D).

Most growers utilizing supplemental lighting report that production time is often reduced and that young plants are of higher quality (increased rooting, stem diameter and branching) and often flower earlier upon transplant. Additionally, when the ambient DLI is low (<7 $mol{\cdot}m^{-2}{\cdot}d^{-1}$) plugs of some species grown under LEDs providing ≥10% blue light are generally more compact (reduced leaf area and stem elongation), greener or have more pigmentation (anthocyanins) than those grown under HPS lamps or no supplemental lighting. Another group of growers use low-intensity LED photoperiodic lighting for 16 to 24 $h{\cdot}d^{-1}$ during young plant production and report reduced production time compared to no electric lighting (Figure 1E).

As the use of LED supplemental lighting increases, more questions surface. For example, since LEDs are much more energy-efficient to operate than HPS lamps, is there any benefit from running them continuously at a lower intensity even if the sun is out? Alternatively, is it more beneficial to run LEDs at a higher intensity in the morning, when it's cloudy and in the evening? There's value in addressing these questions, even though basic plant physiology tells us that plants can only utilize a certain quantity of light (light saturation point) for photosynthesis and anything beyond this is wasted energy.

Additionally, most commercially available LED fixtures only provide red and blue light, which can make plant observation a little more challenging, especially when it's dark. Therefore, we also wanted to determine how the addition of white light, mainly for human applications, would affect plug production.

Our objectives were to quantify plug quality and production time under 1) continuous 16-hour or instantaneous threshold supplemental lighting with HPS lamps or high-intensity LED top lighting; and 2) under low-intensity LED photoperiodic lighting with and without far-red light and compare these methods to plugs receiving no electric lighting.

The study

Seeds of *Petunia x hybrida* Ramblin' Peach Glow, *Impatiens walleriana* Accent Premium Salmon, *Gerbera jamesonii* Jaguar Deep Orange, wax begonia (*Begonia semperflorens* Bada Bing Scarlet) and tuberous begonia (*Begonia x tuberosa* Nonstop Rose Petticoat) were sown in 128-cell trays at a commercial greenhouse. One week later, trays were placed in a glass-glazed greenhouse at Michigan State University (MSU) in East Lansing, Michigan (lat. 40° N), with an air temperature set point of 72F (22C) and a vapor pressure deficit of 0.3 kPa maintained by injecting steam. Seedlings were hand irrigated as needed with reverse osmosis water supplemented with water-soluble fertilizer that provided 60 ppm nitrogen.

		Supplemental lighting				Photoperiod lighting			
	Control	HPS 16-h 70 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$	HPS threshold 90 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$	LED 16-h 70 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$	LED threshold 90 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$	Philips 16-h R:W:FR	Philips 16-h R:W	GE 16-h R:W:FR	GE 24-h R:W:FR
				Total no. of hours of operation					
Nov.-Dec.	0	448	357	448	357	448	448	448	672
Jan.-Feb.	0	448	403	448	403	448	448	448	672
Feb.-Mar.	0	448	319	448	319	448	448	448	672
				DLI ($mol{\cdot}m^{-2}{\cdot}d^{-1}$)					
Nov.-Dec.	4.8	9.7	9.4	9.9	10.0	5.7	5.4	5.5	5.7
Jan.-Feb.	5.5	9.9	10.1	9.7	10.3	5.9	5.8	5.6	6.0
Feb.-Mar.	7.5	12.9	11.8	11.7	11.2	8.5	8.6	8.7	7.9

Table 1. The total hours of operation and daily light integral (DLI) for no electric lighting, threshold and 16-hour high-pressure sodium (HPS) and light-emitting diode (LED) supplemental lighting, and 16- and 24-hour photoperiodic lighting for the four-week study.

Plug trays were placed under each of nine lighting treatments that included a control (natural daylength with no electric lighting), four supplemental lighting treatments with either HPS or LED fixtures, and four photoperiodic treatments with LED lamps (Figure 2). Supplemental lighting treatments consisted of high-intensity 200-watt LED fixtures (Philips GP-TOPlight DRW-MB) providing a light ratio (%) of 10:5:85 blue:green:red (B:G:R) or 400-watt HPS lamps (P.L. Light Systems) providing a PPFD of 70 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (on continuously for 16-$h \cdot d^{-1}$).

These same HPS lamps and LED fixtures were also used in instantaneous threshold supplemental lighting treatments (on from 6:00 to 8:00 a.m. and 5:00 to 10:00 p.m. and only on between 8:00 a.m. to 5:00 p.m. when outside PPFD was <185 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and switched off when >370 $\mu mol \cdot m^{-2} \cdot s^{-1}$) providing a PPFD of 90 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Photoperiodic lighting treatments consisted of screw-in low intensity 14-watt LED lamps providing 2 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of a light ratio (%) of 6:15:77:2 B:G:R:far-red (Philips GreenPower LED flowering DR:W) or screw-in low intensity 15-watt LED lamps providing 7:12:35:46 B:G:R:FR (DR:W:FR) for 16-$h \cdot d^{-1}$ or 10-W LEDs providing 3:17:48:32 B:G:R:FR (GE Arize Greenhouse Pro Photoperiodic LED Lamp) for 16 or 24-$h \cdot d^{-1}$.

Since our continuous supplemental lighting treatments (70 $\mu mol \cdot m^{-2} \cdot s^{-1}$) were on for 16-$h \cdot d^{-1}$ they operated a total of 448 or 672 hours during the four or six weeks of production, respectively (Table 1). In addition to sunlight, plugs under these treatments received an additional 5 $mol \cdot m^{-2} \cdot d^{-1}$ of supplemental lighting.

On the other hand, our threshold supplemental lighting at 90 $\mu mol \cdot m^{-2} \cdot s^{-1}$ provided 2.3 $mol \cdot m^{-2} \cdot d^{-1}$ as fixtures were on each day from 6:00 to 8:00 a.m. and 5:00 to 10:00 p.m. On very cloudy days, the lamps could potentially continue operating from 8:00 a.m. to 5:00 p.m. and provide an additional 4.2 $mol \cdot m^{-2} \cdot d^{-1}$ of supplemental light. During January and February, our threshold lamps ran for 403 hours and provided a very similar DLI during the four weeks of production (Table 1).

After four or six weeks (begonia only), plugs were subsequently transplanted into 4- or 4.5-in. pots filled with a commercial soilless media and finished in a greenhouse with an air temperature set point of 68F (20C) (petunia, begonia and impatiens) under the LED top lighting fixtures mentioned above or 72F (22C) under HPS lamps (gerbera).

Stay tuned for our second article in the four-part series where we'll share the results of our study looking at the effects of light quality, quantity and duration on plug production.

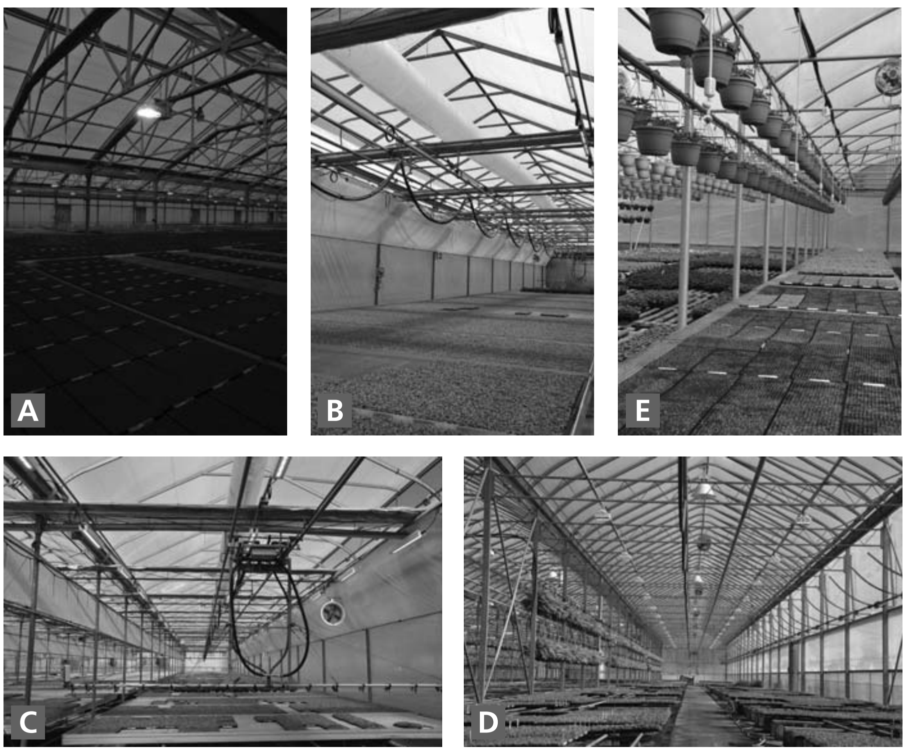

Figure 1. Supplemental lighting of young plants utilizing A) high-pressure sodium lamps, B-D) various commercially available high-intensity light emitting diode (LED) fixtures or E) LED photoperiodic lighting.

Allison Hurt is a M.S. student and Roberto G. Lopez is an Assistant Professor and Controlled Environment/Floriculture Extension Specialist in the Department of Horticulture at Michigan State University. **The authors gratefully acknowledge Ball Horticultural Company and Syngenta Flowers for providing seed, C. Raker and Sons for seed sowing, Philips Lighting, HortAmericas, The Western Michigan Greenhouse Association, and The Metro Detroit Flower Growers' Association for funding, and Nathan DuRussel for greenhouse assistance.**

Figure 2. A) Examples of high-pressure sodium (HPS), B) light-emitting diode (LED) Top lighting and C) photoperiod treatments (wire mesh was used to reduce light intensity).