The plug business moved out of the introductory phase and is part way through the growth stage. We have experienced rapid growth in the last two years. This phase generally sees the entrance and exit of many firms and a high degree of price competition as new firms try to attract business.

What can we expect in the next five-year period?

1. *Plug size.* While some growers are looking for an even smaller cell than the 600 plus tray, I visualize a growing movement to a larger plug. This reflects the movement to 4", gallon and basket production. Quick turnover demands a larger-sized plug rather than something much less than one-half inch in diameter.
2. *Plug popper.* Most users of plugs will have one or more poppers within three years. The payback will be rapid reflecting ease of dislodging and reduction in loss of damaged plants.
3. *Pre-filled trays.* We will see a slow but steady increase in procurement of pre-filled pots and trays. Why invest in equipment often used for only a few months when someone else can provide a uniform mix and deliver just prior to seeding?
4. *Quality seed.* Seed companies will continue to upgrade the quality of seed. We can expect more uniform and higher germination in future years.
5. *Synthetic media.* Don't be surprised if one or more "new" products find their way into plug production.
6. *Exporting plugs.* A market might well develop for plugs in Europe.
7. *Late season demand for plugs.* A great opportunity to extend the bedding plant season.
8. *Price competition.* The dust will settle as the industry moves into the mature stage. We will see a modest number of wholesale producers specializing in plugs.
9. *Mechanical transplanting.* Just around the corner. It will require a highly uniform product.
10. *Synthetic "seeds".* A dream but possibly a reality in 5 to 10 years.
11. *Direct sale of "plugs" to customers.* The larger-sized plugs lend themselves to this forecast becoming reality.

In summary, the plug business will continue to grow at a rapid rate through the eighties. There are still many growers who are yet to be convinced about the merits of plugs. Change will continue to occur as growers consider the merits of producing their own plugs or buying from a specialist.

PLUG UPDATE 1986

Dr. David S. Koranski
Department of Horticulture, Iowa State University, Ames, IA 50011

Single-cell-plant production, or plug production, has mechanized the floriculture industry. Plug production provides several advantages not found in the traditional bedding plant methodology. Mechanization has made the processes of seeding, growing, and transplanting more efficient; time, space, and labor are optimized. Single-cell plants are more vigorous, resulting in a reduction in time needed to produce a crop, thus allowing two or more crops in one season. There are some special considerations a grower needs to think about before producing plugs, however. A substantial initial investment is necessary for germination facilities, mechanical seeders, and trays. The germination and growing-on of the seedlings requires a controlled environment with accurate monitoring devices to provide the proper levels of light, temperature, moisture, gases, and nutrients.

Much progress has been made in plug production over the last few years. In this article, the basic skills and cultural requirements needed for plug production, as well as information obtained from research observations, will be discussed.

Seeders

Mechanical seeders manufactured continue to expand in number and improve in quality each season. These machines increase the speed and accuracy of seed placement. Individual seeders already offer the grower a variety of options. One new option will allow the operator to use smaller amounts of seed in the machine. Many changes in equipment currently on the drawing board will have an impact on the seeders used in the future.

The seeder choice depends on the size of the operation and the types, size, and shapes of seeds most frequently sown. A grower who is just starting to produce plugs might purchase an inexpensive machine until becoming familiar with the difficulties associated with plug culture. A seeder should have the capability of handling many different sizes of plug trays. In addition, the seeder should have a calibration system that allows manual or automatic adjustments for manifold, height, vacuum, pressure, vibration, tilt, rpm's, etc. Any or all of these adjustment features are a plus for that system.

It is important for growers to assess their needs for accuracy, speed, type of seed to be sown, and future expansion before making a commitment to purchase a particular type of seeder. Purchasing a seeder is a major commitment, and one needs to consider the overall system that will be used. With so many new options in the planning stage, it might be a good idea to wait one year before purchasing a new seeder.

Plug trays

The grower can choose from many different sizes and shapes of plug trays. We have found one of the most important characteristics of a plug tray is its depth in relation to the air porosity of the medium in the tray cells. A 6-inch pot containing peat and vermiculite will have an air porosity of approximately 20 percent and, thus, excellent drainage. The same medium in a 406-cell plug tray would have an air porosity of approximately 1 to 2 percent. The difference is the depth of the container. At least a 2-inch column of soil is needed to drain water. The deeper the cell, the more oxygen. Many growers are trying to germinate with 0 percent air porosity in small plug cells.

Germination Techniques

Seed germination is one of the major obstacles challenging the plug grower. The success or failure of these germinating methods usually depends on the ability to achieve uniform control of the environmental conditions. If optimum levels of moisture, temperature, and light are not achieved, difficulties in obtaining a high germination percentage can be encountered. Many germination methods have been used successfully. Some of the methods include controlled environment rooms, sweat chambers, and greenhouses or other structures with intermittent mist.

Culture for germination

Successful seed germination is dependent on light, soil temperature, and moisture levels. Light is not necessary for germination, but emergence of the radical and hypocotyl is essential for subsequent seedling growth. We have been able to directly relate the physiological disorder,. water stem, to inadequate light levels. Water stem is observed as translucency in stems, mainly on petunia and impatiens. The condition develops with 1 to 2 days after germination occurs. Light levels below 400 footcandles (fc) are believed to be a direct cause of water stem. Other influencing factors include suboptimum night temperature, low levels of nitrogen and calcium, and cultivar sensitivity. Water stem, though usually fatal, can be prevented by the provision of light intensity of 400 fc or greater.

Soil temperature is very important for germination. Uniform temperature must be maintained throughout the germination facilities. Different cultivars need different temperatures for optimum germination. A grower can use the information on seed packages as guidelines, but a high germination percentage requires adjusting these guidelines to the grower's facilities and testing small quantities of seed for germination in plug trays. Through our research, we have determined that geraniums germinate best at 70° to 72°F; begonias, 82° to 85°F; and impatiens, 75° to 78°F. Optimum germination for petunias is 75° to 78°F; salvia, 75°F; and vinca, 75° to 78°F.

Air circulation is essential for uniform temperature in a facility where the lamps are the source of heat. A recording thermometer, or thermograph, is very helpful in monitoring air temperature; soil temperature is approximately 2°F lower than the air temperature. Bottom heat, such as root-zone heat, can provide the proper temperatures for bench germination.

The success or failure of plug germination is directly related to the moisture applied to the seed. Too much moisture doesn't allow enough oxygen to reach the seed which can result in desiccation and death of the seed. In most of our research studies, we have provided moisture by using fine mist with droplet size of 20-60 microns and this system has provided ample moisture and oxygen for optimum seed germination. The system consists of combining air and water to provide small water droplet sizes. The size of the water particles can be changed by using a regulator. Preliminary studies have been conducted by using fog -- 5 microns. The results are similar to the fine mist. Clogging of the nozzles by hard water does occur and can be corrected by using a filter system. Propagation mist has a droplet size of 300 to 500 microns, which is too large to allow oxygen to reach the seed.

The temperature and moisture requirements are determined by the crop and can generally be divided into three regimes for three major bedding plant crops: petunia, begonia, and impatiens. Petunias germinate best at 75°F and with 70 to 80 percent humidity. Once the seeds have germinated, the growing medium can be allowed to partly dry out between waterings. Begonias germinate and grow well in an 80°F and 90 percent humidity regime. Impatiens germinate best at 75-78°F and an intermediate moisture level. A grower installing a new germination facility should consider "zoning" the germination facility to provide different temperatures and humidities. Zoning should provide the grower with better germination percentages than would germinating in only one environment. Humidity may be monitored with devices such as a dew point hygrometer or an aspirated psychrometer.

Germination medium

One of the problems most frequently encountered in growing plugs is the provision of a suitable germination medium. Because of the small size of the container, the medium may present serious problems. These problems include fluctuations in: moisture content, aeration, pH, soluble salt levels, and nutrient levels. Therefore, a desirable medium should have a high buffer capacity, a high cation exchange, a high water-holding capacity, and a broad particle size distribution to ensure proper drainage. Difficulties are encountered in obtaining optimum growth for begonias, impatiens, and petunias if they are grown in the same medium under similar environmental conditions. A medium with 20 to 25 percent air porosity is excellent for petunia germination, whereas begonias require only 10 to 15 percent air porosity (Table 1) Perlite can be added to the petunia medium to increase the air porosity. Calcined clay can be incorporated into the medium at 2 to 5 percent to improve the buffer capacity and aeration. Vermiculite can be added to the begonia medium to decrease the air porosity, and increase the cation exchange capacity.

Quantities of nutrients that should be mixed with the medium will vary with different sources of media, environments, water quality, and crops to be grown. Commercial mixes are becoming very popular with growers because of the uniformity of the mix and the convenience. Growers must realize that commercial mixes usually contain a nutrient charge. More importantly, the nutrient charge will vary from one commercial mix to another. It is extremely important to test the mix to determine its nutrient content. Dry growers can burn seedlings if the medium has a high nutrient charge. In our experiments, the best pH range at the start of the germination period for all annuals tested was from 5.2 to 6.0.

Little difference in germination has been observed in different media. The major difference observed was related to airspace. Optimum air porosity is a result of good particle size distribution. A lack of variation in the particle size of the medium's constituents may contribute to poor germination and poor-quality seedlings. A medium must have the appropriate physical properties to allow it to dry partially between waterings. We have observed numerous flats in which the germination percentage was very low. Close examination of the medium indicated a lack of water drainage as the probable cause. The particles of the medium were similar in size, and they compacted with watering, preventing sufficient drainage. The seeds may have not survived because of a lack of oxygen caused by a water-saturated medium. Careful preparation of the medium and testing it for drainage in the different-sized germination containers should prevent serious problems. Calcined clay may be added at 3 to 5 percent to improve aeration.

Water quality

As it is important to know the quality of the medium, so it is important to know the quality of the water. A germination medium of top quality may be of no value if the water applied is of poor quality. Bicarbonate, fluoride, chloride, sodium, and boron levels will cause major difficulties if they exist in excess. Bicarbonate levels can be neutralized with sulfuric, nitric, or phosphoric acid. If the other elements are present, a water purification system should be seriously considered.

Germination facilities

1. *Germination rooms.* Germination rooms are environmentally controlled rooms or chambers in which seeded plug trays can be placed to germinate. They are designed so that the trays may be stacked vertically on movable carts and rolled out of the room for observation, or for the transport of the germinated seedlings to a growing-on area. Most of the heat for the growth room is supplied by cool-white fluorescent lamps. Air conditioning is usually added to the chambers to provide a uniform temperature. Seedlings should not be hand-watered. Better results are obtained with the addition of a fog or mist system, 5 and 20 microns, respectively. These systems increase the humidity at plant level, which is important for optimum germination. Hand-watering can result in seeds being washed out of plug cells. Generally, only spot watering is needed when fog and mist systems are used. Seed trays, depending on the crop, usually remain in germination rooms approximately 2 weeks.

The walls of a germination room can be constructed of exterior plywood. The inner compartments should be at least 3 feet wide so that carts containing plug trays can be wheeled into each section. A slanted roof is used to prevent water droplets from falling on the seed flats. When high-pressure mist or fog is not used, a false ceiling with perforated holes can be substituted for the slanted ceiling. Cool air would then be forced through the holes to help maintain uniform temperature within the room. Cool-white fluorescent tubes are installed between the compartments and are placed 8 to 10 inches horizontally or vertically from the trays. The light intensity measured at plant level should be 400 or more fc for most crops.

2. *Sweat chamber.* Though very similar to germination rooms, sweat chambers are designed for germination only. Therefore, seed trays remain in the

sweat chamber for 2 to 4 days, or until the radical, or new root, emerges. A 90 percent relative humidity is maintained by mixing air and water at 15 pounds of pressure. An 80°F temperature is provided by hot-water pipes located at the perimeter of the chamber's walls. Sweat chambers provide a very controlled environment. Different temperature-humidity requirements can be obtained for different crops. Growers who have optimum control of the environment in their growing-on facilities usually have success with this method of germination. Problems arise when these young seedlings are removed from a dark, moist environment and brought into a dry, high light-intensity greenhouse. These seedlings are at a sensitive stage and require gradual adjustment to the greenhouse environment. To help ease the adjustment of seedlings to the greenhouse environment, high output fluorescent tubes, or High Intensity Discharge (HID) lamps should be installed in the chamber to provide 400 fc of light. An additional low light-intensity area of the greenhouse can also provide a controlled moisture and temperature regime before moving the seedlings into the growing-on area.

To construct a walk-in sweat chamber, exterior plywood walls can be built and lined with polyethylene. A high-pressure mist or fog system should be placed in the middle and at the top of the chamber. The moisture droplet size should be 5 to 80 microns to allow adequate oxygen to reach the seed. The best uniformity of moisture distribution can be attained by very little air movement. Too much air movement can cause uneven distribution and drying in some areas. Uniform moisture distribution is one advantage of the sweat chamber. Heat is added by passing hot water through 1 1/4-inch pipe placed in the chamber around the inside walls. This method allows a uniform 80°F (±1°F) to be maintained.

3. *Germination on benches.* Germination on benches allows the advantage of close inspection of the plug trays. Root-zone, perimeter, or overhead heating systems should emit approximately 70 BTUs per square foot to provide optimum temperatures. Overhead fog or mist systems supply the necessary moisture. It is difficult to use irrigation booms for smaller seeds. The large water droplet size inhibits oxygen penetration to the seed. Some growers use capillary mats on the bench, especially if using root-zone heating without fog. The mats act to supply moisture to the plug trays and reduce the drying conditions of root-zone heating.

HID lamps provide supplemental light energy for seedling development after germination. Maintaining uniform conditions at plant level is a major task, but necessary for optimum germination and subsequent growth and development of the seedlings. Depending on the crop, plug seedlings may remain on the germination benches for 1 to 4 weeks before being moved to a growing-on area. Containerized and movable benches are becoming very popular with growers and work well for germination. Containerized benches can be easily moved to different growing regions on special tracks in the greenhouse without the need for handling the individual trays.

The germination facility a grower should use depends on the size of the operation and the feasibility of achieving uniform environmental control in the germination area. The key is uniform temperature and moisture control. Small growers, unless specializing in plugs, often do not have adequate greenhouse bench space to germinate plugs. The solution to this problem is to take advantage of stacking the plug trays vertically in a special germination room or sweat chamber that has controlled humidity and temperature. Growers with older greenhouses should consider germination rooms or sweat chambers. Older facilities usually are not designed for the precise control needed for temperature and humidity. A large grower may choose to germinate plugs on greenhouse benches provided that environmental control is possible. Benches allow easy access to the seedlings for care and observation.

Temperature, moisture, and light for growing-on

When seedlings are removed from the germination area to a growing-on area, they must be allowed time to adjust to the different environment. The first move, to Stage A, is to a greenhouse that can provide 70° to 80°F soil temperatures for 2 to 5 weeks. The plug seedlings should be watered daily, preferably with overhead mist at 60° to 70°F. Uniformity of the moisture application will determine the uniformity of the growth and development of the seedlings. Turning or rotating flats also may be beneficial.

Field observations have shown that petunia seedlings placed immediately under supplementary HID lamps grow and develop much more rapidly, and flower approximately 1 to 2 weeks sooner. The light intensity should range from 450 to 1000 fc under the HID lights. Four crops that we have tested have been shown to benefit from supplemental lighting. Optimum growth has been observed when impatiens were provided with 2 to 2½ weeks of supplemental lighting; petunias, 2 weeks; begonias, 2½ to 4 weeks; and geraniums, 4 weeks. Growers should keep careful observations on the crop. Chlorosis or bleaching is a good indication that too much light is being supplied.

Light intensity and quality are still important factors for seedling growth in Stage B. A higher light intensity, 4000 to 6000 fc, encourages compact growth. Impatiens are sensitive to high temperatures and high light intensity and benefit from being shaded beginning in mid-April. This is especially important once they begin to flower.

In addition, the growth of seedlings can be controlled by the amount of water they receive, as well as by their ambient and soil temperature. For slower growth, the amount of moisture applied can be reduced. However, depending on the plug size, some seedlings cannot be allowed to lose turgidity. Stunting and flower delay may result from the lowered temperatures. For rapid, lush seedling growth, moisture availability should be constant and combined with 75°F temperatures.

Growth-regulator control of plugs

Seedlings growing under conditions of low light intensity, temperatures above 75°F, and high moisture are likely to elongate. Application of chemical growth regulators is necessary when the environment can no longer be adequately controlled, as in late spring.

The application time for the growth regulator is one of the key factors in the success of growing quality plug seedlings. The growth retardant should be applied before the seedlings begin to elongate. Plug seedlings can be treated at earlier stages of growth and development than transplanted seedlings. To achieve the best results with chemical growth regulators, the first application should be made during Stage A, when the seedlings first begin to elongate, and are 1 to 2 centimeters (1/2 inch) in diameter, or at the first or second true-leaf stage. Because some compounds may inhibit root development, the root system should be examined to ensure that there is active growth before growth regulators are applied. Seedlings also should be of uniform size at the time of treatment to obtain consistent results.

The method of application of chemical growth regulators to plug seedlings is similar to that for cell packs. A fine droplet size is desirable for uniform coverage and penetration of the foliage. The amount of material applied (milligrams of active ingredient per flat) should be monitored and controlled so that the same amount is being applied to each flat. We believe the most suitable time to apply chemicals is approximately 2 hours after sunrise on a cloudy day because the stomates in the leaves are open fully and can allow adequate penetration of the chemical.

Nutrition for growing-on

Nutrition is of special importance in the growing-on stage. We have conducted some preliminary experiments that have shown excellent results with feeding petunias two days after sowing with 50 ppm of a 20-10-20 fertilizer. The experiment was conducted by using 20, 50 and 75 ppm at every irrigation. The 50 ppm treatment provided the best plant growth and development.

Soil tests should be taken at least every 2 weeks. The most common problems as determined from soil tests have been high soluble salts, high nitrates, and low phosphorus. Several thorough irrigations with clear water will leach the salts and nitrates. Phosphorus can be incorporated into the medium as superphosphate (0-20-0). Phosphorus has also been detected at excessive levels. This element can tie up iron, resulting in iron deficiency. Excessive phosphorus can be leached out of soilless media with several thorough irrigations.

Low pH can tie up magnesium and calcium, causing a deficiency of these elements. Magnesium deficiency usually is evident as yellow chlorosis on leaves in the lower portion and the middle of the plant. Marigolds and petunias seem to be more susceptible to magnesium deficiency than most other annuals. Raising the pH and adding magnesium sulfate (Epsom salts) usually corrects this problem. High pH (6.8 or higher) is a common result of continuous use of fertilizer solutions containing a high concentration of calcium nitrate. Iron deficiency may result from this higher pH, appearing as classical interveinal chlorosis. Even though iron may not be lacking in the soil, the high pH makes it unavailable to the plant. Iron chelate and iron sulfate can be used, with caution, to remedy the problem. A fertilizer mixture with minor elements and a relatively high percentage of nitrate nitrogen is used to maintain optimum nutrition and optimum pH.

Timing and scheduling

One of the many advantages of growing plugs is the reduction in the time needed to produce a crop. Timing for plug production must piece all stages of growth together with the environmental conditions for a smooth-flowing schedule.

Most seedlings need to remain in the chamber 7 to 14 days. If left in the chamber too long, the 75° to 80°F chamber temperatures and relatively low 400 to 500 fc light intensity will cause stretching and nonuniform development. Field observations have shown that the earlier that seedlings are removed from the chamber (from the first sign of germination to when the cotyledons begin to unfold) and placed in Stage A (a 75°F greenhouse equipped with supplemental

HID lighting), the more rapidly and fully the seedlings develop. In addition, stretching is greatly reduced. If seedlings must remain in the chamber for any extended time, the temperature should be lowered as much as possible and the light intensity increased to help prevent stretching.

The warm, 70° to 75°F, temperatures of Stage A serve to acclimatize the tender, newly germinated seedlings and to provide an environment that, when supplied with moisture and fertilizer, encourages rapid growth and development. Most crops remain in Stage A for 2 to 3 weeks or until the first set of true leaves begins to appear. Begonias may remain much longer, even up to the time of transplanting.

As the true leaves begin to develop, seedlings may be moved to Stage B, a cooler, 55° to 60°F, area to "hold" until needed, or a warm 75° to 80°F area for continued rapid, succulent growth. We have found that the flowering of petunias may be delayed by subjecting plants to temperatures below 60°F before the plants have initiated flowers. Seedlings remain in Stage B until transplanted, approximately 2 to 3, or more, weeks.

Once transplanted, the seedlings can again be "held" at 55° to 60°F or encouraged to develop and flower in approximately 2 weeks by providing 70° to 75°F temperatures, moisture, and fertilizer.

In summary, many advancements have been made in the plug industry. Growers seeking to enter into plug production or upgrade their current system should thoroughly investigate all options available in equipment and structures. Success in plug production still remains dependent on the attention made to detail: temperature, humidity, moisture, light, and nutrition. Every crop has different requirements for optimum growth. This article presents only a few of the requirements that we have observed. Growers must now apply this information to their own greenhouse growing environments.