Techniques for Manipulating Seeds and Seedlings for High Quality Flower Seedlings©

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INTRODUCTION

Seed and seeding quality are like many things; hard to define but easy to recognize when one sees it. Seedling quality is becoming more important all the time with increasing emphasis on plug production and automation. When seeds are sown in open seedling flats it is very hard tell if germination is 70% or 90%, but a plug tray with 392 cells, which has 353 seedlings (90%) looks very different from one with 274 seedlings (70%).

MEASURING SEED AND SEEDLING QUALITY

Before a discussion of seedling quality we need to identify what we're talking about. Quality is measured by germination percentage, seedling vigor, and uniformity.

Perhaps the most familiar measure of seed and seedling quality is germination percentage, which is simply how many seeds germinate. This measures how many of the seeds are alive and capable of at least the earliest stages of germination under controlled conditions, and therefore gives a maximum number of seedlings one could expect to produce under perfect conditions.

Vigor is a more difficult factor to measure, since it is made up of many things, such as speed of germination, size of cotyledons, and ability to germinate under adverse conditions. Vigor tests may involve measurement of speed of germination or ability to germinate under less than ideal conditions.

A more recent measure of seed quality involves measuring the uniformity of the seedlings produced. This is difficult to measure, but is very useful for plug growers who need to have uniform seedlings in a tray.

Seed producers and distributors use all three of these criteria to evaluate seed quality. The simplest test is a determination of germination percentage in a Petri plate on blotter paper in a laboratory. As discussed above, this can determine the number of live seeds, but often is not a good predictor of seed performance under greenhouse conditions.

Many seed companies are now testing seed under realistic greenhouse conditions. Seed is sown into plug trays and cared for in ways as close to grower conditions as possible. In these tests the seeds that develop into normal seedlings are counted, resulting in a test that is more meaningful to the end user of the seed. Often in these tests a subjective evaluation of uniformity is performed.

A recent innovation in seed testing is the use of a computer connected to a camera to evaluate seedlings. This method removes the subjectivity of a visual rating. Computerized imaging systems can incorporate size of cotyledons, uniformity, speed of germination, and many other factors into a rating. Because the computer looks at every plug tray the same way, there is no variability that can occur when seedlings are evaluated by technicians using a rating scale.

MANIPULATING SEED FOR MAXIMUM SEED QUALITY

The maximum performance of any seed is determined by the genetic potential, which is incorporated during breeding. Seed production companies have been breeding for improved germination for many years and continue to make improvements.

Many plants in nature produce seeds that are not uniform in germination ability. There is a survival advantage in this. For example, if all seeds germinated at the same time and a drought followed an entire generation would be lost. By germinating over a long time, plants in nature enhance the likelihood of some plants surviving to bloom and produce seeds again.

This variable germination often found in wild plants is not desirable in cultivation. Therefore, one of the first selections plant breeders make in developing cultivated plants to be propagated from seed is to select for uniform germination. As is the case with all breeding, this can be a long process, requiring repeated selection.

Even while breeding for increased germination uniformity, the plant breeder will also be selecting for seedling vigor. This is sometimes, though not always, associated with large cotyledons. The breeder will watch and select for good root development, rapid leaf development and ability to tolerate unfavorable germination conditions. Of course beautiful flowers, a long bloom season, strong stems, good branching, and other valuable characteristics are being assessed as well.

Even after the breeder has done his or her best, for maximum potential germination the seed must be produced under carefully defined conditions and processed after harvest to preserve the germination potential. Many seed producers have research departments that investigate ways to produce the highest quality seeds. This may involve determining the best nutrient regime for the seed parent, the best temperature, the best stage to harvest the seed, and so on. Seeds after harvest must be brought to an appropriate moisture level for maximum storage.

Sometimes the seeds that are produced still do not meet the requirements for maximum production. Some seeds have fuzz or tails on the seed making mechanical sowing difficult. The fuzz or tail can be mechanically or chemically removed. Some seeds have odd shapes, are extremely small, or have a lightweight relative to their size. These seeds can be pelleted or coated for ease of handling.

Some seeds are primed, which is a laboratory process that begins germination, and then stops the process before there is any external evidence of germination. Primed seeds are often more resistant to adverse germination conditions and may germinate more quickly than nonprimed seed.

MANIPULATING SEED STORAGE TO MAINTAIN SEED QUALITY

Seeds, like all living things, require a favorable environment to survive. Unfortunately for many seeds, they often have to share their living space with human beings with different environmental expectations. Seeds often mark time in offices, in break rooms, or in a box next to the seeder. These environments are usually more suited to human comfort than seeds.

Each type of seed has its own ideal conditions for storage, but some generalizations apply. In general, seeds store longest with the highest viability and vigor if stored cool (approximately 5 ºC) with low humidity (25% to 30%). If humidity cannot be controlled, at least store the seeds in the refrigerator. For example, research shows impatiens seeds deteriorate at 72 ºF (22 ºC) at any relative humidity higher than 25%, yet retain acceptable quality at 41 ºF (5 ºC) even up to 45% relative humidity.

Most seeds from quality seed producers are packed in packets which block moisture movement. If the packet is unopened, then only temperature control is needed, since the humidity in the packet was determined when it was packed and sealed.

While temperature is most important, for maximum seed quality humidity must be controlled as well. For best success, construct a seed storage chamber with controlled temperature and humidity. Desiccant-type dehumidifiers are the only practical way to reduce humidity below 30%.

Do not open seed packages until ready to sow; whenever possible use an entire package per sowing. If an open package must be stored, return the open packet to low temperature and dry air conditions as soon as possible. Do not re-seal a seed package until the seeds have had been in dry conditions for at least 24 h to remove any moisture absorbed from the air.

STAGES OF SEEDLING GROWTH

Researchers in the field of plug production initially developed a one through four stage series to describe the development of seedlings. Since then other stages have been added to describe other critical phases for seedling quality:

Stage 0:	Seed production, handling, storage, and sowing. *Often forgotten, as discussed above the care of the seeds prior to planting has a large effect on the final product.*
Stage 1:	Radicle emergence. *Requires careful attention to temperature and moisture. Lack of attention in this stage can result in lack of uniformity.*
Stage 1½:	Radicle penetration into the medium. *A newly defined stage, this stage also requires careful attention to moisture or seedlings will be variable.*
Stage 2:	Cotyledon expansion. *At this stage root development is important and the seedling is more resistant to environmental stresses.*
Stage 3:	True leaf development. *The majority of plug growth occurs in this stage.*
Stage 4:	Mature/holding. *The crop is "toned" to make it suitable for shipping and transplant.*

MANIPULATING GERMINATION MEDIA FOR MAXIMUM SEEDLING QUALITY

Good quality seedlings are built from the ground up. Use a uniform disease-free seedling medium for germination. Be sure trays are filled uniformly. Do not stack the trays, since this will compress the medium resulting in uneven growth.

Test the medium before sowing. Test at least for pH and electrical conductivity (E.C.). A full test for all nutrients is even better. Most growers use one germination medium for all crops, using a pH between 5.5 and 6.0 and an E.C. between 0.5 and 0.75 mmhos$\cdot$cm^{-1}. If your water is alkaline use medium with a pH at the low end of the range.

Some crops perform best at a medium pH outside the usual range or alter the medium pH as they grow. These crops often benefit from specific media (Table 1).

Table 1. Suggested germination medium pH for selected crops (soilless medium). Used with permission from research conducted by Bailey, Nelson, Fonteno, Lee, and Huang at North Carolina State University, Raleigh, North Carolina.

Crop	pH	reason
Celosia (*Celosia argentea*)	6.0 to 6.8	prevent Fe and Mn toxicity
Dianthus	6.0 to 6.8	prevent Ca deficiency and ammonium toxicity
Geranium (*Pelargonium*)	6.0 to 6.8	prevent Fe and Mn toxicity
Marigold (especially African) (*Tagetes erecta, T. patula*)	6.0 to 6.8	prevent Fe and Mn toxicity
Pansy (*Viola*)	5.4 to 5.8	prevent B and Fe deficiency and avoid *Thielaviopsis* root rot
Petunia	5.4 to 5.8	prevent B and Fe deficiency
Salvia	5.4 to 5.8	prevent B deficiency
Snapdragon (*Antirrhinum majus*)	5.4 to 5.8	prevent B and Fe deficiency
Vinca (*Catharanthus roseus*)	5.4 to 5.8	prevent B and Fe deficiency and avoid *Thielaviopsis* root rot

MANIPULATING LIGHT FOR HIGHEST SEEDLING QUALITY

Almost all floriculture crops grown from seed either benefit from light during germination or are unaffected by light. Exceptions include vinca (*Catharanthus*) and *Gazania*, which germinate best in total darkness.

Not long ago, when all seeds were germinated in the greenhouse with natural light, there was no need to be concerned with supplying light to improve germination. With increased use of germination chambers however, light requirements are more of an issue.

As little as 10 fc (100 lux) of light will improve impatiens germination. This is approximately the amount of light necessary for most people to be able to read a newspaper at arms-length. Keep in mind that this is the amount of light needed at the seed, not at the edge of a plug tray at the edge of a pallet. Cool white florescent lights are economical and supply sufficient light.

Seedlings must receive more light immediately after germination to avoid elongation and are usually removed from the germination chamber at this point. Maintain light levels between 1000 and 2500 fc (10,000 to 30,000 lux) during Stages 2 and 3. As seedlings mature, light levels may be increased up to 5000 fc (54,000 lux) if temperature can be controlled. Typically, mature seedlings can tolerate as much light as can be provided in an average greenhouse. Light may need to be reduced for temperature control, but when temperature control can be maintained the highest quality seedlings are produced with the highest light intensity during Stage 4.

MANIPULATING TEMPERATURE FOR MAXIMUM SEEDLING QUALITY

Each plant species, and often even each cultivar, has its own optimum temperature for germination. Fortunately most seeds germinate well over a temperature range

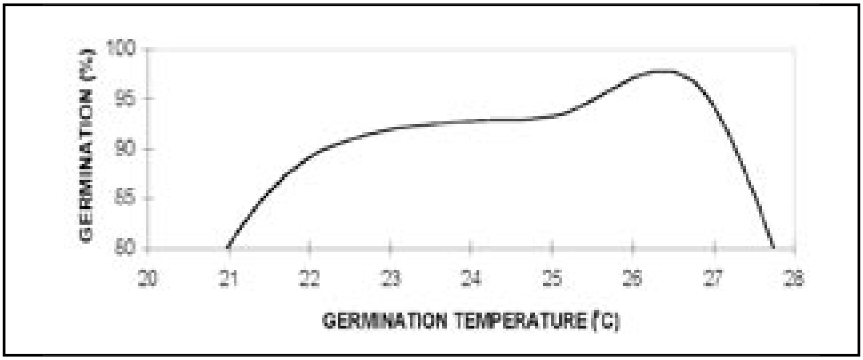

Figure 1. Percent germination of impatiens seed over a temperature range.

of several degrees. For example, impatiens germination only varies by one or two between 22 and 27 °C (72 and 80 °F), yet drops off very quickly outside this optimum range (Fig. 1).

Many growers find they can germinate all of their crops with a moderate temperature germination chamber or greenhouse set at approximately 23 °C (74 °F) and a warm temperature chamber or greenhouse set at approximately 26 °C (79 °F) (Table 2).

Table 2. Stage 1 germination conditions.

Moderate chamber approximately 23 °C (74 °F)
Aster (*Callistephus chinensis*), coleus (*Solenostemon scutellarioides*), *Cosmos*, *Dianthus*, dusty miller (*Centurea cineraria, Senecio cineraria*), *Gazania*, geranium (*Pelargonium*), hypoestes (*Hypoestes sanguinolenta*), impatiens (*Impatiens walleriana*), marigold (*Tagetes*), pansy (*Viola*), snapdragon (*Antirrhinum majus*), *Zinnia*.
Warm chamber approximately 26 °C (79 °F)
Ageratum (*Ageratum houstonianum*), alyssum (*Lobularia maritima*), *Begonia*, *Browallia*, celosia (*Celosia argentea*), lisianthus (*Eustoma grandiflorum*), lobelia (*Lobelia erinus*), New Guinea impatiens (*Impatiens howkeri*), *Nicotiana*, *Petunia*, portulaca (*Portulaca grandiflora*), *Salvia*, torenia (*Torenia fournieri*), *Verbena*, vinca (*Catharanthus roseus*).

MANIPULATING MOISTURE AND AIR: CRITICAL FOR QUALITY SEEDLINGS

Seeds need both water and the oxygen in air to complete germination. Most seedling production practices are a balance between providing enough water without reducing oxygen available to the seed or seedling. Because seedlings are typically grown in trays with a very small medium volume, changes occur quickly, and irrigation may be needed several times per day.

During Stage 1 sufficient water must be available to hydrate the seed and maintain uniform moisture, yet not prevent oxygen from the air from reaching the seed. Most seeds are more susceptible to lack of water than lack of oxygen during early germination, and should be kept uniformly moist during Stage 1. Drying at this stage will cause variability of the seedlings and deformed seedlings. Seeds of a few species, such as verbena, are damaged by high moisture levels and must be kept barely moist during germination.

A well-designed germination chamber helps to ensure proper moisture during the earliest stages of germination. A properly designed germination chamber will have 100% relative humidity so the plug trays neither gain nor lose water during Stage 1. If trays are watered thoroughly before placing them in the chamber they will usually supply sufficient water to the seed for Stage 1.

Perhaps the most critical stage for moisture management is during Stage 1½. During this phase of seedling growth the radicle (seed root) must anchor itself into the medium and grow downward while the cotyledons expand. The root needs oxygen to grow and will not penetrate into medium saturated with water. At the same time, these very small seedlings are extremely sensitive to drying, again resulting in variability and malformed seedlings. For these reasons, frequent, light irrigations at this stage are necessary, as well as a very high relative humidity to slow drying.

Once the radicle has penetrated the medium the irrigation objectives change. The medium can be allowed to dry more thoroughly to ensure good air supply to the roots for rapid growth. Once the root is visible at the bottom of the plug cell irrigate by thoroughly saturating the medium, then allowing the soil to become dry between irrigations.

MANIPULATING WATER QUALITY FOR QUALITY SEEDLINGS

Seedlings are composed of about 90% water. For this reason alone we know irrigation water is important in seedling production. Having adequate water is important, but the quality of the water is equally important. Since water is an excellent solvent it will dissolve some of the minerals it flows past. These minerals can be useful to plants, such as magnesium, or potentially toxic, such as fluoride. All these components of the irrigation water can affect seedlings. Even the temperature of the water can have an effect.

Water temperature can play a major role in production of seedlings. Since plug cells are so small growers tend to water frequently. If the irrigation water is cold, germination and growth is slowed due to reduced temperature. Growers of plugs often have a water heater with a mixing valve to mix hot water with cold water so the crop can be irrigated with water at 21 to 24 °C (70 to 75 °F).

Perhaps the most talked about aspect of water quality is the combination of high pH and high alkalinity. It is important to remember these are two separate components of water quality. It is possible to have high pH without high alkalinity. The pH of absolutely pure water is 7, exactly neutral, but irrigation water is almost never pure. The pH of irrigation water is determined by what is dissolved in it. Even a little of a basic compound dissolved in water can cause the pH to become high. Although the pH can be quite high even with just a little dissolved material, the pH in this situation is of little concern to the grower, since the water contains only a little of the material making it basic.

Some water, however, contains considerable quantities of dissolved materials like carbonates and bicarbonates. A familiar carbonate is limestone, composed primarily of calcium carbonate, used to raise the pH of soils. The bicarbonate familiar to most people is baking soda, sodium bicarbonate, used in cooking and as an antacid. It is the carbonate and bicarbonate content we are concerned with when we discuss alkalinity of water, since these compounds, like limestone and baking soda, can neutralize acids and increase the pH of germination media. Watering with water with high alkalinity is like adding limestone or baking soda to your potting medium every time you water. The pH of the medium can increase rapidly causing nutrients to become unavailable.

Carbonates and bicarbonates are not the only materials dissolved in irrigation water. Many minerals can be found as well, some helpful, some harmful, and some neither. The level of concern depends on the amount in the water. The following table gives guidelines for irrigation water suitable for most seedlings (Table 3).

Table 3. Desirable levels of selected characteristics of irrigation water for production of most seedlings.

Characteristic	Desirable level
pH	5 to 7
Total electrical conductivity	<0.7 $mmhos \cdot cm^{-1}$
Total alkalinity	<100 $mg \cdot L^{-1}$ expressed as $CaCO_3$
Chloride	<100 $mg \cdot L^{-1}$
Sulfate	<200 $mg \cdot L^{-1}$
Sodium	<50 $mg \cdot L^{-1}$
Iron	<5 $mg \cdot L^{-1}$
Boron	<0.5 $mg \cdot L^{-1}$
Zinc	<5 $mg \cdot L^{-1}$
Manganese	<2 $mg \cdot L^{-1}$
Copper	<0.2 $mg \cdot L^{-1}$
Aluminum	<5 $mg \cdot L^{-1}$
Molybdenum	<0.02 $mg \cdot L^{-1}$
Fluoride	<1 $mg \cdot L^{-1}$

* $mg \cdot L^{-1}$ is equivalent to ppm.

* To convert sodium from milliequivalents (meq) to mg·L, divide by 23.

* Sensitive crops may require lower levels of some compounds.

* Nitrate- and ammonium-form nitrogen, phosphorous, potassium, calcium, and magnesium are often reported on water analyses. Levels of these nutrients are not given since the level in irrigation water seldom is significant in comparison to soluble fertilizer levels, although adjustments to fertilization practices may be necessary.

Irrigation water that is only slightly outside the recommended range often can be used as long as cultural modifications are made. Acid-forming fertilizers can balance the alkalinity of water that is only slightly above the desired level. The label on a fertilizer bag indicates if the fertilizer is acid-forming. For example, one brand of 20N–20P–20K soluble fertilizer has a potential acidity of 597 pounds of calcium carbonate per ton, while 15N–15P–15K, with the same balance of N–P–K, has a potential acidity of only 261 pounds of calcium carbonate per ton. All other things being equal, the 20–20–20 would do a better job of preventing an increase in pH due to high alkalinity water than the 15N–15P–15K.

If water for seedling production is significantly outside the recommended range, some modifications must be made. The simplest solution to a water quality problem is to switch to water that does not have the problem. This is seldom possible, although sometimes a well drilled into a different aquifer can give a great improvement in water quality. Sometimes a partial supply of excellent water is available to supplement the poor quality water though. Examples might be a small pond or even city water. Rainwater can be collected and stored for use. By mixing the limited supply of good quality water with the poor quality water a grower can often dilute the compound in excess to a level that is acceptable.

Water can be purified by reverse-osmosis, which essentially filters out the impurities with a membrane filter. Reverse osmosis is expensive, however, and should be considered only after other options have been found to be unacceptable.

The most common solution to water with high alkalinity is the addition of acid to neutralize the carbonates and bicarbonates. Phosphoric, nitric, sulfuric, and organic acids are used most often. The following table lists approximate rates of acids to bring irrigation water to a level acceptable for seeding growth (Table 4).

Table 4. Approximate rates of acids to bring irrigation water to a level acceptable for seeding growth.

Multiply:	By	To get:
	Using 75% phosphoric acid	
Milliequivalents of carbonate per liter	7	Fluid ounces of 75% phosphoric acid per 1000 gal
ppm calcium carbonate	0.14	Fluid ounces of 75% phosphoric acid per 1000 gal
NOTE: Each fluid ounce of phosphoric acid per 1000 gal will result in 6.6 ppm phosphate in the irrigation solution.		
	Using 98% sulfuric acid	
Milliequivalents of carbonate per liter	3.2	Fluid ounces of 98% sulfuric acid per 1000 gal
ppm calcium carbonate	0.064	Fluid ounces of 98% sulfuric acid per 1000 gal
	Using 67% nitric acid	
Milliequivalents of carbonate per liter	10.5	Fluid ounces of 67% nitric acid per 1000 gal
ppm calcium carbonate	0.21	Fluid ounces of 67% nitric acid per 1000 gal
NOTE: Each fluid ounce of nitric acid per 1000 gal will result in 1.7 ppm nitrogen in the irrigation solution.		

(Adapted from *Greenhouse Operation And Management*, 4th ed. Paul V. Nelson with permission.)

Problems cannot be identified and no solutions can be tried until the irrigation water has been tested. Many laboratories will test irrigation water and offer suggestions on how to work with the water. Ideally the irrigation water will be tested, then a second sample will be resubmitted after acid has been added, a new fertilizer added, or some other remedy begun.

Irrigation water should be tested at least once per year, although once every 6 months is not too often. Tests should also be run any time the water source has changed. Even well water can change after a prolonged drought or an unusually wet season.

MANIPULATING SEEDLING NUTRITION FOR QUALITY SEEDLINGS

Most germination media contain very little fertility. Research has demonstrated that seedlings develop fastest with highest quality with fertilizer available immediately after germination. Therefore, most growers fertilize seedlings from Stage 1½ to the end of Stage 2 with 50 to 75 ppm nitrogen and potassium (K_2O). Lack of fertility at this stage increases variability in the seedlings.

Most growers increase fertilization during Stage 3 to 75 to 150 ppm nitrogen and potassium (K_2O). The quantity and type of fertilizer used will influence seedling growth. High fertility gives the fastest crop time, but may result in shoots too large in relation to the roots. Low fertility levels help maintain a good root to shoot balance, but increase crop time and result in light-colored foliage.

The amount of phosphorous in the fertilizer program will determine plant habit. Low phosphorous levels keep the seedlings short while maintaining dark foliage. Use phosphorous (P_2O_5) at about 20% of the nitrogen level. Lower rates can result in symptoms of phosphorus deficiency, including lower leaf chlorosis. Table 5 lists common nutritional deficiencies in seedling production.

Table 5. Common nutritional deficiencies in seedling production.

Problem	Symptoms	Comments
Iron deficiency	Chlorosis between veins on upper leaves	Iron uptake is inhibited by high pH, low temperature, poor root growth
Boron deficiency	Death of growing points, misshapen young leaves	Boron uptake is reduced by high pH
Calcium deficiency	Clubby root growth, death of growing point, chlorotic leaf margins	Use a fertilizer with calcium to avoid deficiency

MANIPULATING SEEDLING HEIGHT WITH PLANT GROWTH REGULATING CHEMICALS

Oftentimes even after manipulating temperature, light, air, water and nutrition, seedlings may grow too tall. Use of moderate amounts of plant-growth-regulating chemicals can result in seedlings with the desirable shoot to root ratio.

The most common plant growth regulating chemicals used for height control of seedlings are daminozide (Alar, B-Nine), chlormequat (CCC, cycocel), ancimidol (A-Rest), and paclobutrazol (Cultar, Bonzi). Each plant, chemical, and environment will interact with differing results, so no specific recommendations can be made in an overview such as this. However, there are some general conclusions that can be made about these chemicals.

In general, plants will grow out of the effects of daminozide most quickly and grow out of paclobutrazol most slowly. The others are intermediate. Therefore, for slight control of seedling height with little long-term effect daminozide is preferred. For more dramatic height control, paclobutrazol should be used.

Plant growth regulating chemicals can be applied as a spray to the foliage or by saturating the substrate with a drench. In general, the duration of the effect of a foliar spray is less than the effect of a substrate drench. A spray is generally less costly due to less total chemical used and less labor for application. However, spray applications are more difficult to apply uniformly, which can result in uneven growth. Drenches often can be applied more uniformly resulting in less variability of growth.

Many growers find that applying two plant-growth-regulating chemicals mixed together gives better height control with less risk of phytotoxicity than applying either chemical alone. The exact concentration of chemicals to be used varies, but in general, growers often apply each chemical at half the rate it would be used if used alone.

SUMMARY

Seedling quality is determined first by the genetics of the plant and the conditions under which the seed was produced and stored. However, the seedling grower must manipulate many aspects of the environment to unlock the maximum potential that each seed holds.

Temperate Treatment of Flower Bulbs: Manipulating Flowering Times©

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WINTER BULBS

In order to understand how the flowering time of bulbs can be manipulated, it is critical to comprehend that bulbs are perennials, and that their life cycle is generated by temperature. Our discussion here is limited to winter bulbs, and they are named thus as they require cold temperature to activate their flowering cycle.

Manipulating Flowering Time. If a commercial grower were to be totally dependent on nature's built-in clock in bulbs, he/she would be forced to flood the market with his/her whole crop of tulip (*Tulipa* sp.) blooms during a single week in springtime and so depress the market price to a catastrophic level. No grower of tulips would survive. This problem cannot be solved by simply planting the tulip bulb earlier or later in autumn, because the bulb is too clever to fall for this trick. It will stubbornly catch up if it is planted too late, or slow down if it is planted too early. It will still flower in that same week in springtime.

In order to fool the bulb we have to do something else. The triggering mechanism that makes the bulb respond to new growth after its resting period is a seasonal change of climate. This sensitivity of the bulb to changes in temperature has to be exploited by the commercial grower in order to get the bulb to flower in a week different from its natural one.

The flower grower will lift tulips bulbs from the ground only at the start of their dormant season in early summer, when the foliage has died down naturally, and the bulbs are full of food. After the bulbs have been washed, graded, and sorted into size groups, they are placed in special chambers in which the air temperature and humidity are carefully controlled. The bulbs are placed in mesh trays so that they can be exposed to forced air ventilation. This is necessary to keep them healthy.

The temperature and humidity in the chamber are designed to mimic nature in the bulb's natural habitat. The natural home of tulips, for example, is southwest Central Asia, and in the normal course of events, the onset of autumn (with a consequent drop in temperature) will set off a response inside the bulb. Root formation will be triggered so that the roots will be ready in time to feed the plant with nutrients and water from the soil during its natural winter and spring growth period.