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Water Management

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SUMMARY. Important components of water management for transplant production include water quality, the frequency and volume of water application, and the method of application. Water quality factors of concern are alkalinity, soluble salts including sodium absorption ratio (SAR), and ions at potentially toxic concentrations including boron and fluoride. The available water in individual transplant cells is influence by container size and geometry, medium particle size, medium moisture release characteristics, and wetting agents but is primarily determined by irrigation frequency and the amount of water applied at each irrigation. Irrigation scheduling can be done using several methods but is influenced by the crop stage, the water volume applied, and the frequency of drying desired. Transplants can be watered by hose and breaker, stationary sprinklers, traveling boom sprinklers, fog nozzles, or subirrigation. The outcome of experiments testing effects of transplant size, transplant age and fertilizer rates are all influenced by water management.

Recently, the trend in ornamental and vegetable transplant production is to grow transplants in plug cell trays. Broadcast sowing of seeds in seedling flats and then hand transplanting the seedling has been replaced by sowing a single seed in a small cell, thereby individualizing the transplant. The root system remains intact during transplanting thereby reducing shock and subsequent establishment time. Plug producers have decreased the amount of labor that is needed to grow a crop and increased the amount of mechanization used. Plug production has both increased efficiency and complicated the process of production at the same time. The decreased size of the root zone requires more precise water and fertilization management. Some plug cells may be as small as 2 cm^3 (800 plug flat).

The objective of this review is to consider the key components of water management for transplant production. The first issue addressed *is* ***wbat*** type of water is applied as defined by water quality. The second issue considered *is* ***wben*** and ***how mucb*** water is applied, including the methods of irrigation scheduling. The third topic is ***how*** the water is applied using commercial irrigation practices. For each topic, relevant research information and popular grower-related information is reviewed.

Water quality

There are several characteristics of water quality that can drastically affect the quality of transplants through changes in the nutrient status and pH of the growing medium. Much of the recent water quality-related research is based on information in the USDA Agriculture Handbook 60 (Allison et al., 1954). In the handbook, four major quality characteristics of an irrigation water were recognized: 1) concentration of soluble salts; 2) relative proportion of sodium to other cations; 3) concentration of boron and other toxic elements; and 4) bicarbonate concentrations as related to the concentration of calcium plus magnesium. However, Spurway (1938) presented a review of water quality issues for greenhouses much earlier and covered many of the same topics. The most recent complete discussions of water quality related to greenhouse and container crop production have been by Biernbaum (1995) and Petersen (1996) and for plugs by Styer and Koranski (1997). Water quality related to plant production in containers is also covered by Bailey (1997); Bunt (1988); Lang (1996); Nelson (1991); Reed (1997); Styer (1996); and Vetanovetz and Knauss (1988).A characterization of water samples from commercial greenhouses in the United States including the pH, EC, and macronutrient concentrations was recently published by Argo et al. (1997). Their findings were similar to those of Ludwig and Peterson (1984) as reported in Rose et al. (1995).

ALKALINITY. Alkalinity is a measure of bicarbonate and carbonate concentration in the water determined by titration with dilute acids to a pH endpoint

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of 4.5. Alkalinity, not water pH, causes changes in the pH of the root medium. Argo and Biernbaum (1996) have shown how alkalinity in combination with fertilizer reaction influences changes in media pH for impatiens *(Impatienswallerana* Hook. F.) grown in pots. Water alkalinity of 20, 120, or 320 mg?L^{-1} bicarbonate resulted in either rising, stable or falling pH depending on the combination with either a basic, neutral or acidic reaction fertilizer.

A number of authors warn that alkalinity levels >80 mg?L^{-1} bicarbonate will cause the pH of the media in plug cells to increase (Biernbaum, 1995; Lang, 1996; Styer, 1996; Styer and Koranski, 1997). An alkalinity concentration of between 40 and 80 mg?L^{-1} is generally recommended to maintain a stable medium pH. However, Biernbaum (1994) points out that such a simple approach to bicarbonate concentration may not be the best guideline for all crops. When growing plugs there is a very small amount of medium to manage and changes in medium pH can occur much faster than for larger pots of media. The amount of water applied and leaching may also influence medium pH changes due to alkaline water. Routine monitoring of the root medium pH is the best method to determine the alkalinity level that will maintain a balanced medium pH for a given system. If rising medium pH is a problem during production, either an acidifying fertilizer (high in NH_4) or the addition of acid to the irrigation water can be used. High ammonium fertilizers (>20%) are not recommended for plugs due to the increased growth that may occur. Methods of acidification are reviewed by Biernbaum (1995).

SOLUBLE SALTS OR ELECTRICAL CONDUCTIVITY. High levels of soluble salts in the irrigation water or excess application of fertilizer salts can lead to a buildup of salts in the media over time and will limit water uptake due to osmotic effects. Seed germination and transplant production is usually accomplished with frequent, nonsaturating applications of water to maintain media moisture. This provides little or no leaching. Consequently, the irrigation water must be fairly pure and the grower should pay close attention to the levels of salts in the root medium. Sodium and chloride are the most common nonnutrient salts in irrigation water. When Na or Cl are excessive (>60 mg?L^{-1}) some type of water purification is recommended for plug production (Reed, 1997; Biernbaum, 1995; Styer (1996) recommends that sodium absorption ratio (SAR) values should be <2.0 and that the concentration of sodium ions be <40 ppm. According to Styer (1996), high SAR value will cause a medium to hold more water because of the increase in solute potential negativity, which will result in lower 0_2 content and thereby reduce potential for root growth.

OTHER CONCERNS. Certain elements found in irrigation water can be phytotoxic at very low concentrations. Boron and fluorine are the most common concerns (Biernbaum, 1995; Argo et al., 1997). Hardness from calcium and magnesium bicarbonates may create problems with plugging of spray nozzles and residue on plant foliage, particularly if iron is also present. Sulfur concentrations in irrigation water are commonly less than is recommended for crop production (20 to 30 mg?L^{-1}) and sulfur is often not added to water-soluble fertilizers (Reddy et al., 1994). With very pure water, calcium and magnesium may also be limiting if not supplied on a regular basis with water-soluble fertilizer.

WATER TREATMENT. If alternative water sources are not available, water purification is often justified for high value transplants (Reed, 1997). Options include filtration, acidification, softening and reverse osmosis, ozonation, bromination or chlorination. Depending on the water source, treatment may be required for plant pathogens and algae.

Irrigation scheduling:Amount of available water

Before considering methods for irrigation scheduling, it is important to determine which factors influence the amount of water that is available to the plant. The volume of the plug cell, the shape of the plug cell, the medium particle size, the medium water release characteristics and, possibly, the moisture content of the medium at the time of flat filling can influence available water content in the root zone.

CONTAINER SIZE AND GEOMETRY. The volume of plug or transplant cells ranges from 2 cm^3 (800 cells/flat) to 25 cm^3 (128 cell/flat, deep tray). The volume is a not only a function of the number of cells but the depth and geometry. Square cells typically have a greater volume than round cells. At saturation, the amount of available water may range from 40% to 60% of the volume or from 1 to 15 mL.

Milks et al. (1989) point out that shallowness of containers results in too much water and, therefore, too little air in the root zone. A relationship exists between the ratio of air space to available water, and the shape of the plug cell. In general, deeper cells hold more air in the germination medium than the same medium in a shallower cell. The decrease in air content of shallower cells is due to the decreased effect that gravity has on water drainage. The shorter the column of water the more water will be retained in the container, because adhesive forces exceed those of gravity.

MEDIUM PARTICLE SIZE. Air space is also directly related to pore size of the medium. After a container medium is irrigated to saturation, the first water to drain out the bottom of the cell is that which filled the macropores or air space of the medium. If the pore space of the medium is sufficiently small to provide greater forces for adhesion than gravity, a capillary fringe (a zone of saturation) can form in the bottom of larger containers (Foth, 1990). Because of the reduced height of a plug cell this capillary fringe of the root zone may include the entire cell height, and cause the entire cell to remain saturated.

Bilderback and Fonteno (1987) effectively demonstrated the interaction of container size and medium particle size in the determination of air space. The percent air space increased with both larger containers and larger pore space which was a result of larger medium particle size. This relationship has been mathematically modeled (Fonteno, 1989; Milks et al., 1989). In very shallow containers, medium particle size likely has very little effect on aeration at saturation.

MEDIUM MOISTURE CONTENT AT TRAY FILLING. It has been reported that air space in plug cells (a 288-cell tray) can be increased from the normal 2% to 7% when the moisture content of the mix is increased from 60% to 70% before the flat is filled (Milks et al., 1989). The minimum advisable pre-flat-filling minimum water content is

50% on a weight basis. Medium shrinkage after irrigation may occur at higher medium moisture contents. The most important recommendation is a consistent initial medium water content to provide uniform plug production over time since flat filling practices and equipment often dictate acceptable medium moisture content.

MEDIUM MOISTURE RELEASE CHARACTERISTICS. Along with air space, the amount of water that is available to the seedling is a function of the medium. Even though there may be moisture in the medium, it may not be available to the plant. The forces of adhesion to the soil particles may be greater than the water potential of the seedling roots. Even though two different media contain the same percentage of water on a volume basis the moisture volume or tension can differ based on the nature of the medium (Bilderback and Fonteno, 1987).

WETTING AGENTS. Wetting agents (surfactants) are common1y added to peat-based media to aid in rewetting. The primary effect is on the absorption of water into peat fibers and is more important for very dry peat then peat that already contains some moisture. In taller containers under saturating conditions, the effect of the wetting agent on surface tension can lead to an increase in drainage and air content. Wetting agents can degrade if media are stored for several months. While commonly used materials are not phytotoxic, excessive rates or nonhorticultural wetting agents can result in effects on germination or plant growth.

SUMMARY. Despite the effect of growing container height and root medium properties on air and moisture holding capacity, in most commercial settings air space in the root medium is maintained more by limiting the application ofwater at each irrigation then by container or root medium selection. While in larger containers water must be added to thoroughly moisten the entire medium profile, in shallow containers a less than saturating amount of water can be added without detrimental effects to roots since the water will distribute adequately.

Irrigation scheduling: Methods

SOIL MOISTURE TENSION. Although not commonly done, in larger pots growers can measure the soil moisture tension with a tensiometer which when connected to a climate control computer can be used to determine irrigation frequency (Wilkerson and Samengo, 1992). With plug production, the soil volume is so small that the tensiometer would displace the media.

WATER LOSS PREDICTIONS. Water loss can be predicted using data collected by environmental control computers. Total accumulated solar radiant energy or light intensity can be summed over time and used to schedule irrigations. Solid state mist controllers based on light sensor input are commercially available (Davis Engineering, Calif)

Vapor pressure deficit (VPD) values can also be used to estimate the amount of water that has been used by the plant or has evaporated (Barret, 1996). Vapor pressure is a measure of the partial pressure of water vapor, or the concentration of water in the air. Ambient greenhouse air is rarely saturated while the leaf has intercellular spaces saturated with water vapor. This difference in water potential or concentration is the driving force of transpiration. Climate control computers with automatic watering programs monitor factors that influence leaf temperature (combination of ambient temperature and tight levels), air temperature and relative humidity. With a VPD-based watering system, the computer determines VPD every few seconds and the accumulated VPD becomes an estimate of plantwater use (Barret, 1996). Based on this VPD integral, irrigation frequeny is determined by a target value set by the grower. The magnitude of the target is determined by plant maturity, container size, and the crop that is being grown. In order to set the correct target value some experimentation may need to be done. Close monitoring of the system is needed when first establishing the targetvalue. Commercially available programs have been used successfully for plug production in commercial greenhouses (Miller, 1989).

DETERMINATION BY WEIGHT/GRAVIMETRIC. Determining irrigation scheduling can be done consistently and reproducibly using a scale. Weight loss between the time of a typical irrigation and the point of wilting can be used as an estimate of available water and to schedule irrigations. Argo and Biernbaum. (1994, 1995a, 1995b) used scales with poinsettias *(Euphorbia pulcherrima* Willd. ex Klotzsch) and Easter lilies *(Lilium longiflorum)* to make comparisons between potting media where available water and water use were not identical. Available water is determined as the weight of the flat, medium and plants after an irrigation minus the weight at wilting. Irrigation is usually done when 75% to 85% of the available water is lost. This method is very useful to quantify the method of irrigation or medium moisture content in research situations. Using weight, a repeatable set of parameters that anyone can follow can easily be defined.

Other factors influencing irrigation scheduling

EFFECT OF CROP STAGE. One complication to plug water management is the various water management strategies needed during different stages of crop growth. Commercial transplant or plug production is typically divided into four stages. During Stage 1 of plug production (from sowing to radicle emergence) most plugs need to be at or near rnedium saturation depending on the species to maintain constant contact between the seed and water, Once the radicle starts to penetrate the medium surface, water levels need to be decreased to allow proper root development. Stage 1 can be completed either in a germination chamber supplied with a fog generating system to maintain near 100% relative humidity (Miller, 1989; Stiyer and Koranski, 1997) or out in the greenhouse if uniform moisture can be maintained. Either frequent application of water, covering the seed with a thin layer of medium, perlite, or vermiculite, or covering the trays with a lightweight, frost-protection fabric is necessary to maintain the high level of moisture required to complete stage I in the greenhouse.

High moisture levels during stage 1 are not recommended for all bedding plant species. Bedding plant water requirements during stage 1 have been classified as wet, moist, or dry (Koranski et al. 1991; Kuack, 1991; Stryer and Koranski, 1997). Wet medium is saturated so the seed is surrounded with moisture. Moist medium is wet but not saturated.

Dry medium has little water added before or after sowing and is kept dry until germination begins.

As the transplant continues to mature, moisture levels are decreased to help harden off the plant to increase tolerance to drought stress conditions, and increase the chances for survival during shipping and transplanting (Koranski, 1983). Stage 2 is defined as the period from radicle emergence to formation of the cotyledonarv leaves. Stage 3 is development of the true leaves. Stage 4 is the finishing or hardening stage. In some cases there is a Stage 5 which is storage at cold temperatures before transplanting. Keeping the foliage dry during cold storage is critical to prevent foliar pathogens. Subirrigation is recommended during stage 5.

DRYING THE MEDIUM. Over watering plugs is the most common problem plug growers encounter (Styer and Koranski, 1996). Commercial transplant or plug producers are reportedly concerned about keeping the time between irrigations to <24 to 48 h. A rapid drying time reportedly allows replenishment of the air/oxygen in the root zone and more frequent application of nutrients, if needed. However, growth of seedlings under prolonged high moisture conditions with infrequent irrigation versus rapid drying and frequent irrigation has not been evaluated under controlled conditions. Control of plant growth in containers can be accomplished by keeping plants dry. Unfortunately, dry growing has not been well defined. Allowing plants to wilt and then thoroughly saturating the root media is not as effective at controlling plant size as more frequent small volume applications that do not allow for saturation of the root zone.

Bottom heating also contributes significantly to the drying of the root medium (Sray, 1996). Bottom heating is provided by hot water circulated through pipes under expanded metal bench tops on in concrete floors. Without bottom heating, the root medium temperature can be significantly below air temperature due to evaporative cooling.

VOLUME APPLIED/LEACHING. The volume of water applied can have a large effect on fertilizer retention in the root medium (Biernbaum, 1992). A small amount of leaching can remove soluble fertilizer from the medium and alter the water-soluble fertilizer requirement (Argo and Biernbaum, 1996b). The concentration of nutrients in the root zone from water-soluble fertilizer is very dependent on whether leaching occurs. Lower fertilizer concentrations applied with no leaching can lead to the same nutrient concentration in the root zone as higher fertilizer concentrations applied with leaching (Yelanich and Biernbaum, 1993, 1994; Nelson et al., 1996).

Irrigation methods

There are five major methods for watering plug seedlings: 1) hand watering, 2) stationary sprinklers, 3) traveling boom sprinklers, 4) fog, and 5) subirrigation. Each has its advantages and disadvantages. The water droplet size and the uniformity of the water application will affect the uniformity of the finished product. A general discussion of watering methods for -Plugs can be found in Styer and Koranski (1997) and Lucas (1991).

HAND WATERING. Hand watering is the most flexible method for irrigating portions of an area whether part of a flat, bench or greenhouse. However, labor costs make hand watering the most expensive. It is also hard to achieve the uniformity and small particle size that is needed. If lack of watering uniformity results in reduced plant quality, more money is lost.

STATIONARY SPRINKLERS. Stationary sprinkler systems like those used to finish bedding plants are commonly used for plug irrigation. Nozzles can be on risers coming from below the bench or on suspended water lines over the crop. Uniformity can be a problem. It is hard to design a sprinkler system so that there is little overlap or complete overlap. Droplet size is usually larger than with booms or fog systems.

TRAVELING Booms. One of the most popular choices for plug producers today is boom irrigation. By, mounting spray nozzles on a horizontal pipe moving at a constant speed down the greenhouse a uniform line of water is applied (Lucas, 1991). New advancements like variable speed motors, selectable spray nozzles, and bar codes that can be placed along the path of the boom to control water application and speed of movement have increased the flexibility of this system. The capital cost is offset in large greenhouses where the boom can travel from house to house.

FOG. Very fine, uniform particles (5 µm) of water produced by fog systems can allow maintenance of high moisture levels and relative humidity with very low application rates compared to fine mist (20 to 60 pm) from spray nozzles or large particles typical with hand watering (300 to 500 µm). A high quality, pure water source is required. For some flower crops, plants started with fog grew faster than other watering methods with large droplet size (Ball, 1987). Fog during the first 10 d increased the germination percentage of petunia (*Petunia xhybrida)* (Koranski et al. 1991). Fog is used in germination chambers or in the greenhouse, although it is more practical in germination chambers. In the greenhouse, the high relative humidity from fog can lead to condensation on the glazing surface and dripping. Dripping from the glazing can rapidly destroy plants and disperse media from the small cells.

SUBIRRIGATION. Subirrigation is a popular choice for many potted crops produced in the greenhouse due to uniformity of water application and low labor costs (Biernbaum, 1993)), but presents specialized problems with plug production. Medium in the shallow cells of plug trays rapidly becomes saturated when in contact with water. Less than saturating applications of water are not possible, and increased particle size of the root medium does little to reduce water uptake. Root pruning is also not generally possible with subirrigation on tables or cement floors because the bottom of the flats cannot be dried out adequately.

Subirrigation has been used successfully for production of vegetable transplants with large (128-cell), polystyrene flats that will float on the irrigation water (Leskovar et al., 1994). In this system, the plants are suspended on wires between irrigations which allows root pruning. The time between irrigations is 2 to 3 d. Transplants grown with the flotation system were found to be acceptable as long as there was minimum hardening before planting in the field (Leskovar et al. 1994). One of the advantages of subirrigation is that the foliage remains dry during an irrigation. One of the main motivations for the transplant float system was to reduce the spread of bacterial diseases in tomato

(Lycopersi con esculentum) transplants that occurred with overhead watering.

Conclusions

The key to successful growing in any plug tray is water management (Koranski and Karlovich, 1989). successful water management depends on ,what, when and how much is applied, and how it is applied. Whether in research or production situations, aspects of water management must be quantified to allow consistency and reproducibility within a tray and over time.

The effect of water quality or application method have often not been considered in experimentation with vegetable transplant production. The effects of container size, container geometry, and root restriction have been discussed with little apparent consideration for the relationship of these variables to the amount of irrigation water applied and possible effects on medium pH, EC, or nutrient content (Latimer, 1991, Lescovar et al., 1994; Leskovar and Cantliffe, 1992; Liptav and Edwards, 1994; Marsh and Paul, 1988; Maynard et al., 1996; Weston, 1988; Weston and Zandstra, 1986). For example, a comparison of the effect of transplant container volumes from 7 to 70 cm^3 could be done by seeding all the plants on the same date and then transplanting on the same date, for example 30 d later. Not only would the plants in the 7 cm^3 cell be ready to transplant after 15 d and therefore likely sitting stalled for 15 d, but the high volume of water necessary to keep those plants alive in the small cell for the remaining 15 d could have a dramatic effect on root medium pH and EC (nutrient content) depending on whether pure water or high alkalinity water was used for irrigations. Clearly, water quality, irrigation method (leaching) and fertilization method could have a large effect on the outcome of this experiment. Reporting medium pH and EC at the end of the transplant production phase would be very helpful. As an alternative, the experiment could also be done with different seeding dates leading up to the same transplanting date so the maturity of the plant for a given cell size is reached at the same time and the comparison is more of cell size/ transplant age as opposed to maturity (root restriction) or degree of possible pH or nutrient stress.

Uniformity and a well developed root system are essential for transplants whether planting in the greenhouse or the field. However, it may be useful to identify other desirable characteristics for different types of transplants. Types of transplants include a seedling going from one container size to another in the greenhouse, a flower or vegetable transplant that will be shipped and then sit in a retail store or outside display area with minimal care prior to ending up in a residential garden, a flower or vegetable transplant that will go direct from the greenhouse to an irrigated field, or a transplant that will be planted in a nonirrigated area.

Future research or problem areas related to water quality and irrigation method for transplant production should include

1) Uniform reporting of research methods including type of water and method of irrigation.
2) Methods for controlling or eliminating algae on the medium surface. Algae promote development of fungus gnats (Baradysia sp.), which transfer disease.
3) Production of a well developed root system and a transplant that is hard enough to survive mechanical transplanting but soft enough to grow rapidly after transplanting.
4) Further identification and definition of the optimum medium moisture status in combination with fertility programs during various stages of plug production to minimize production time while maintaining transplant survival and regrowth potential, including the relation with growth retardant chemicals.
5) Methods to reduce root medium water availability during the early stages of production while maximizing root medium water availability in the final stage when plants are large.
6) Maintenance of plant vigor and reduction of the use of foliar and root disease control chemicals through water management techniques.

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