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Nutrition of Floricultural Crops: How Far Have We Come?

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According to Seeley (1979), even though the Society for Horticultural Science was formed in 1903, it wasn't until the 1930s that research papers on the subject of floriculture were published in our journal. There were, however, numerous college and university bulletins about floricultural crops which included fertilizer studies (for example, Blake, 1915).

Despite the sluggish start, in the last 25 years, in the American Society of Horticultural Science's three journals (*Journal of the American Society for Horticultural Science*, *HortScience*, and *HortTechnology*) alone, there have been over 240 publications relating to nutrition of floricultural crops. Journals such as *Scientia Horticulturae*, *Journal of Plant Nutrition*, *Agrochemica*, *Journal of Environmental Horticulture* as well as others also publish papers on this topic. Thus, the focus of this article will be on research published in ASHS journals. Even with this narrowed focus, only a sampling of the research that has occurred can be mentioned here.

Floriculture in its broadest sense involves growth and development physiology, culture, management and postharvest physiology of cut flowers, potted flowering and foliage plants, cacti and carnivorous plants, bedding plants and herbaceous perennials including forbs and geophytes. Adequate elemental content of these plants is critical at all growth stages to ensure a marketable product. For a more complete picture of the art and science of floriculture see the "History of U. S. Floriculture: the People, Events and Technology that shaped the Past 100 Years" (Greenhouse Grower, 1999). An additional historical-based article about USDA research including floriculture crops from 1862 to 1940 is by Griesbach and Berberich (1995).

To begin an article like this, one should discuss essential elements and how essentiality is determined. With addition of nickel, there are now 17 elements (carbon, hydrogen, oxygen, nitrogen, phosphorous, sulfur, potassium, magnesium, calcium, iron, manganese, boron, copper, zinc, molybdenum, chlorine) required for a plant to complete its life cycle—one of the criteria for determining if an element is essential. In 1983, Joiner, Poole, and Conover published an in depth review article titled "Nutrition and Fertilization of Ornamental Greenhouse Crops" which covers a discussion of the essential elements and brings together much of the floriculture literature as it broaches the topics of factors affecting the frequency and quantity of fertilizer application and nutrient/fertilizer requirements for the then major crops.

The first paper in an ASHS publication (*Proceedings of the American Society for Horticultural Science*) specifically dealing with nutrition of floriculture crops was titled "A Method for Studying Nutrient Deficiencies in Greenhouse Crops (Laurie and Mc Elwee, 1934). This paper describes a continuous drip system used to apply four different nutrient solutions (complete, N, P, K) to a number of different floricultural crops. The plants were grown in acid-washed sand. The solutions were prepared from reagent grade chemicals that included the six macroelements plus Fe, Mn, Na, and Cl. Visual observations of deficiency were recorded. Sound familiar? Since then researchers have basically expanded on this theme using or creating new technology to help identify and quantify nutrient deficiencies, sufficiencies and toxicities in floricultural crops. Each paper presents a different twist on classic nutrient studies all ultimately aimed at understanding how nutrients interact during the plant's life cycle.

MEDIA AND MIXES

Since the development of the University of California system mixes (Baker, 1957) and the Cornell peat-lite mixes (Boodley and Sheldrake, 1967), more and more floriculturists have been and still are experimenting with nonsoil containing mixes and additives (for example, hydrophilic polymers, Blodgett, et al., 1993). This is in comparison to ornamentals

such as trees and shrubs, which are still mainly field grown. That is not to say that floriculture researchers don't work in the field and in soil (herbaceous perennials—Duarte and Perry, 1988), it's just that the main emphases have been on alternative mixes in greenhouse or controlled environments. Research on media has ranged from hydroponics to peat-based mixes to bark-based mixes (Albrecht et al., 1980), to sewage sludge/biosolids-based (Chaney et al., 1980; Williams and Nelson, 1992b) or recycled tire-based mixes (Newman et al., 1997) to zeolites (Carlino et al., 1998) to plant by-products such as coir (Meerow, 1994; Wang and Blessington, 1990) as sole or component part(s) of media (Fonteno and Nelson, 1990; Conover and Poole, 1983). Key variables such as physical characteristics, salinity, nutrient and water retention interactions have been the objectives of this research as all of these variables affect nutrient availability to plants (Rupp and Dudley, 1989). The importance of nutrient element interactions with irrigation sources and pH also received attention for many types of mixes (Yelanich and Biernbaum, 1993; Argo and Biernbaum, 1996; Argo and Biernbaum, 1997). Commercial products with and without a nutrient charge have followed suit producing a wide variety of quality, ready-to-use bagged mixes. The end result of commercial use for these different types of mixes is still being governed by grower preference, availability and cost as much as nutrient- and water-retaining capacity and efficacy.

With the great increase in use of nonsoil-based media a different method of mix analysis was needed. The Spurway analysis method used for soils wasn't adequate for these lightweight, organic intensive blends (Westerman, 1990; Markus, 1986). Alternatives to standard soil elemental and pH-EC analysis such as the saturated media extract (SME) (Warncke, 1986) and the pour-through method were developed and compared for different types of mixes (Wright, 1986; Yeager, et al., 1983). Currently, the rhizon soil solution sampler (RSSS) holds promise as a quick, inexpensive, nondestructive method that does not overly disturb pot media for determining pH, EC, NO₃-N and K (Argo et al., 1997). Research on the press-extraction method, specifically developed for plug mix analysis, demonstrated strong correlations for nutrient content, pH and EC with the SME and thus, also shows promise for practical use (Scoggins et al., 2001).

FERTILIZER FORMULATIONS AND DELIVERY SYSTEMS

Research in this area has covered soluble, slowly soluble, and controlled release/encapsulated formulations (Kovacic and Holcomb, 1980) as well as specific elemental source (N. Conover and Poole, 1986; Schrock and Goldsbery, 1982; Woodson and Boodley, 1982a). Many studies have been designed to test the interaction of fertilizer formulation, media type and/or plant cultivar both during specific growth phases and postproduction (Tayama and Carver, 1992; Vetanovetz and Petersen, 1990; Haver and Schuch, 1996; Nell et al, 1997; Starkey and Pederson, 1997).

Nutrients must be diluted to reach the roots or leaves of plants. Thus, the confounding of water and fertilizers (fertigation) and the need to investigate different methods of nutrient solution delivery as well as water quality, alkalinity and pH (Reed, 1996). Research has been done using almost every fertilizer delivery system available from hydroponics (Jensen, 1997; Hickleton et al., 1987) and recirculating nutrient solutions (Woodson and Boodley, 1982b) to sand culture; ebb and flood benches, drip irrigation to sub-irrigation (Kent and Reed, 1996; Todd and Reed, 1998), nutrient film technique (NFT) (Graves, 1983) to foliar sprays of specific elements (Harbaugh and Woltz, 1989; McAvoy and Bible, 1996; Gilliam and Zlesak, 2000). The objectives of these studies are ecologically sound and include minimizing or eliminating runoff, fertilizer applications, leachate (Cox, 1993; Ku and Hershey, 1997; Lang and Pannuk, 1998) and water application as well as recycling of fertilizer or waste water (Sanderson, et al., 1985). Even studies using saline and recycled irrigation water (Koch and Holcomb, 1983; Biernbaum, 1992) have been conducted with an eye

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to the future scarcity and demand for potable water. The mobility of individual elements in a mix is also important and impacts delivery system and formulation (P, Yeager and Barrett, 1984; micronutrients, Broschat and Donselman, 1985). Implementing these studies at the commercial level is much harder as many of these more efficient systems are costly when installed new and even more costly when retrofitted to existing greenhouses. Also, some systems will be better suited for certain greenhouse range sizes and certain crops such as potted plants (Uva, et al., 2001). Still, floriculture researchers have heightened awareness and provided technology transfer to the industry.

NUTRIENT ANALYSIS AND PLANT CONTENT

Understanding the role of nutrients as a driving force for physiological reactions including environmental, stress and postharvest physiology has been broached by numerous researchers and a body of knowledge is beginning to accumulate that will help both scientists and growers come to a better understanding of this complex interaction (Borch et al., 1998; Hansen and Lynch, 1998; Jeong and Lee, 1992; Mankin and Flynn, 1996; Nell et al., 1989; Neumaier et al., 1987; Salac and Fitzgerald, 1983; van Iersel et al., 1998; Wang and Sauls, 1988; Whipker and Hammer, 1997; White and Biernbaum, 1984; Woodson et al., 1984).

Researchers have continued pursuing determinations of deficient/critical (Ca, Hershey and Merritt, 1987; Woltz and Harbaugh, 1986 and Ku and Hershey, 1991; K, Hershey and Paul, 1981; S, Dale et al. 1990), sufficient and toxic concentrations (B, Brown et al., 1999; Fe, Albano et al., 1996; Mo, Hammer and Bailey, 1987; micronutrients, Lee et al., 1996) for many nutrients using leaves of floricultural plants (geranium, Widmer et al., 1986; hydrangea, Bailey and Hammer, 1988; anthurium, Higaki et al., 1992). Unfortunately, sometimes plant response to nutrient concentration is cultivar specific (Mo and poinsettia, Cox, 1992; Mn and N, Reddy and Mills, 1991), thus, making generalizations more difficult. Additionally, research has been necessary for certain crops that require specific, nonessential elements, e.g., aluminum for blue hydrangea flowers (Blom and Piott, 1992) to ensure a marketable crop.

Work continues on estimating the efficiency of plant usage of single elements (Rose et al., 1994) and balances or ratios of elements such as $\text{NH}_4:\text{NO}_3$ (Roude et al., 1991; Cox and Seeley, 1984) Ca and N (Lawton et al., 1989; Smith, et al, 1998), N and S (Huang et al., 1997). However, only recently has root nutrient concentration been studied (Albano and Miller, 2001; Picchioni et al., 2001). Methods for quick determination of elements such as Cardy meters for nitrate and potassium have been used, but produce variable results (Rosen, et al., 1996). Nondestructive methods for determining nutrients are under investigation, e.g., N determination using a chlorophyll meter (Jones, 1998). However, for reliable leaf nutrient analysis a sample still must be taken, digested and analyzed by specific lab procedures.

To date, floriculture has no parallel to DRIS (diagnosis and recommendations integrated systems), which are standard norms available for diagnosing deficiency, sufficiency and toxicity in fruit and some vegetable crops (Parent and Granger, 1989). Floriculture generally tends to use the critical value approach (CVA) to determine the cause of deficiency or toxicity problems. Numerous books/manuals plus a CD-ROM (American Phytopathological Society, 2000) have been developed to bring together tissue standards and pictures identifying nutrient problems for a wide range of crops including floricultural crops (Windsor and Adams, 1987; Reuter and Robinson, 1997; Mills and Jones, 1996). Books devoted to specific floriculture crops such as poinsettias or roses are also available. These indicate how much (fertilizer rate) of which element a particular plant needs as well as the specific elemental concentration in leaves (Ecke, et al., 1990; Langhans, 1987; Armitage, 1993; Nau, 1996; Holcomb, 1994; Rogers and Tija, 1990; Holley and Baker, 1991; De Hertogh and Le Nard, 1993). These books have the advantage of discussing plant nutrition as a part of the production scheme rather than just a table of values.

Trade magazines such as *Greenhouse Grower* and *GrowerTalks* feature new crops with growing schedules that include recommended fertilizer rates. A current text for teaching floriculture crop production and physiology which helps students learn about the role of fertilizers in floriculture crop production is Dole and Wilkins, 1999.

GOING ORGANIC

While parts of most floricultural crops would not be deemed edible (Kelly et al., 2002) and therefore, not a concern for pesticide or fertilizer residue, there is a definite gardening trend of using natural sources of fertilizers such as composts and manures. Such usage was a more common practice 70 or more years ago as noted in Pridham and Thompson (1930) where manure was the preplant fertilizer used for their study on gladiolus. Until recently (Choi and Nelson, 1996; Fitzpatrick et al., 1998; Wilson et al., 2001; Young et al., 2002), floriculturists have left this source of plant nutrients for studies by others. However, it would be easy to incorporate this source of fertilizer into floriculture research as farmers and researchers interested in organic vegetable production have done quite extensive research (Hartz et al., 2000; Korcak, 1992).

THE FUTURE

As predicted by Seeley (1979), sales of cut flowers, bedding plants and potted plants have increased over the last 25 years. Additionally, herbaceous perennials have burst onto the marketing scene. Crops once thought to be minor, such as potted orchids (Britt, 2000), enjoy more sales than those solely attributable to the hobbyist. Tropical cut flowers and foliage are common components of floral designs and the theme for the 21st Century from gardens to wedding bouquets is variety and lots of it! Variety in color, variegation, plant type and habit. The problem for scientists studying plant nutrition is that not all species respond similarly to the same rates of essential and nonessential elements. Thus, the need for trials for each species or even variety. This is juxtaposed with the increased costs of research, reduced government funding and grant opportunities. Additionally, it seems that we are returning to the beginning of the last century in terms of having fewer scientists dedicated solely to plant nutrition who are involved in teaching, research and extension at land-grant universities and colleges.

Thus, research in plant nutrition has a dicey future at best. The rising costs of graduate student stipends (\$20,000 to \$30,000 per year) and the lack of sources willing to commit \$100,000 or more to a 3-year project in plant nutrition make justifying this research difficult. Continuing decreases in federal and state funding leave newer horticulture faculty without technical support. Again, they may become like their predecessors of the 1930s and end up doing most of the physical work themselves. Forming teams to investigate interactions of plant nutrition with insects, diseases and other physiological phenomena may be a solution. Recently, research on the nutrient content of leaves and the interaction with pests (Bagatto et al., 1991; Harbaugh et al., 1983) and diseases (Chase and Poole, 1984) has enjoyed renewed attention and federal funding. For biochemically inclined horticulturists, there are single element pathways that still are incomplete (example S) and interactions with other biochemical and physiological processes (for example secondary compounds) yet to explore. For those genetically inclined the role of nutrients and genetics is very promising and the role of nutrients in signal transduction leaps to mind. Additionally, molecular biologists and plant taxonomists are reclassifying and realigning many plant families and genera. Perhaps more broadly based nutrient requirements or generalizations can be made if we look at floricultural crops more as a group, for example, perennial herbs (geranium) and woody angiosperms (poinsettia and chrysanthemum). Critical choices of crops and mathematical models to extend to crops not tested need to be developed (Dole and Wilkins, 1991; Milks et al., 1989; Parent and Dafir, 1992; Willits et al, 1992). Floriculturists interested in plant nutrition for diagnosing problems may want to revisit the CVA system as the method of choice (Parent and Dafir, 1992).

Technology transfer from university to industry will remain important even though publishing in trade magazines may be viewed as less valuable than journal articles. So, in terms of the plant nutrition researcher directly serving the floricultural industry, there may be an expanding role for individuals with a good background in plant nutrition to serve as the horticultural equivalent of the agronomic crop consultant. These individuals would not only solve grower-related problems, but also could serve as the link between industry and university researchers in terms of identifying needed research and funding. ASHS provides a

mechanism for certification of advisors through the CPH program.

In addition to the challenges of funding, keeping up with the on-going scientific changes will be a struggle. Reviewing the past literature is also a daunting task and one often minimized by graduate students as pivotal articles from the 1950s and 1960s are not included in library computer databases. Researchers need to be careful about key words (additional index words) inclusions on journal articles as that may make the difference whether their paper becomes a reference.

While we, as scientists, have made good progress in reporting repeatable experiments, it is only since 1998 that all floriculture nutrition and related articles have included well-described experimental designs and data analysis methods. This trend should continue in two ways. First, the use of smarter designs should be promoted. For example, incomplete block and response surface designs (Clemens and Morton, 1999) can reduce costs and allow screening of large numbers of treatment factors (including varieties) and complex interactions. Second, data analysis should move beyond linearity and simple mean comparisons. For example, many nutrient response relationships are nonlinear; use of nonlinear methods results in better insight and more efficient use of the data.

Lastly, we will need to revisit and redefine all of plant nutrition in terms of its role in environmental pollution. Fertigating greenhouse floors via heavy leaching losses (McAvoy, 1994) is no longer acceptable (Latimer et al., 1996) and many of our international colleagues are well ahead of us (Papadoupoulos, 1999). We need to reduce and balance fertilizer inputs despite the current minimal cost (Kuehny and McMahan, 1998; Williams and Nelson, 1992a). We need to develop ways to reuse/recycle/reclaim spent mixes rather than tossing them in landfills.

During the 21st century, research challenges—basic and applied as well as those in between—will still present themselves. There will just be fewer floriculturists/horticulturists to solve them.

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