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Bulletin 413
November, 1984

research bulletin

Published by the Colorado Greenhouse Growers' Assoc., Inc. in cooperation with Colorado State University

THIRTY YEARS OF NUTRITION STUDIES AT COLORADO STATE UNIVERSITY

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In which a New Zealander reads the Bulletin and points out some discrepancies. The editor undertakes some philosophic comments on greenhouse nutrition.

For nearly 30 years, CSU, with the financial assistance of the Colorado Flower Growers and the Colorado Greenhouse Growers Association has conducted nutrition research on greenhouse crops. This spring, Dr. Kenneth Young, Plant Diseases Division in Aukland, wrote the editor, pointing out some problems in a few of the Bulletins. One supposes that, in any endeavor, mistakes will be made — else, nothing is going on. It was rewarding that someone took the effort to read the Bulletins. It was also humbling that anyone should find mistakes in publications from this institution. However, 30 years of effort deserves a summary as to the status of plant nutrition in greenhouse production, largely dealing with carnations. Regardless of crop, certain take-home principles are applicable to other species.

Some History

In the late 1960s, Green made a radical departure from the usual manner in which investigators considered plant nutrition in greenhouse practice (Bul. 210-212). The work was based upon terminology that allowed one to separate the major ions as they were actually taken up by a plant, and to investigate carnation and rose feeding with greater precision than previously. Hartman and Holley (Bul. 221, 248-250) followed with additional detail. The original recommendations for carnation nutrition in a constant feed system were published by Hartman and Holley in Bulletin 221:

Chemical	Pounds per 1000 gal. of irrigation water
Potassium Nitrate	5.0
Calcium Nitrate	3.0
Ammonium Nitrate	1.0
Magnesium Sulfate	2.0
11-37-0	1.5
Borax	1 ounce

This feeding solution, intended for a water supply with no other chemical in signficant concentration, provided the following ions:

[1]Professor

Ion	Milliequivalents per liter
Potassium	6.0
Calcium	3.0
Magnesium	2.0
Ammonium	2.5
Nitrate	10.4
Sulfate	2.0
Phosphate	1.1

The total number of positive and negative ions must equal each other. The use of these concentration terms refers to chemicals in the form assimilated by a plant, regardless of the source of that chemical. If units are totally in metric, calculations are much simplified.

A similar nutrient solution for roses in good water, was provided by Sadasivaiah and Holley (Roses, Inc., 1973 (Supplement)):

Chemical	Pounds per 1000 gal. of irrigation water
Potassium Nitrate	1.7
Calcium Nitrate	6.0
Potassium Chloride	1.3
Ammonium Nitrate	0.7
Magnesium Sulfate	1.0
Phosphoric Acid	0.6

This solution provides the following ions:

Ion	Milliequivalents per liter
Potassium	4.1
Calcium	6.0
Magnesium	1.0
Ammonium	1.0
Hydrogen	1.0
Nitrate	9.0
Sulfate	1.0
Phosphate	1.0
Chlorine	2.1

However, the carnation formula, although still used at the research range with some slight modifications, and the rose formula, were shortly found to be insufficient when one considered the fact that very few irrigation supplies in Colorado have nothing in them. In 1968, Hanan, Schekel and Holley found these ranges in common greenhouse water supplies (Bul. 222):

Ion	Meq/l Low	Meq/l High	
Potassium	0	0.15	(Shallow wells and some surface waters)
Calcium	0	9.6	
Magnesium	0.3	5.8	
Sodium	0.6	13.9	
Nitrate	0	1.7	(Shallow wells and some surface waters)
Chloride	0.1	3.1	
Sulfate	0.2	11.5	
Bicarbonate	0	7.5	
Carbonate	0	0.8	
Total Salts (micromhos/cm)	93	1521	

Adequate nutrition of any crop cannot be achieved without due consideration of what is present in the irrigation water. The nutrient solutions given result in about 1300 to 1500 micromhos/cm total salinity. If the water already has 1000 μmhos/cm, then complete injection will seriously increase salinity and drastically reduce crop yield. Thus, a number of Bulletins have dealt with control of salinity in water supplies and how one may overcome the fact that some essential nutrients may be present in excessive amounts (Bul. 229, 251, 253, 305, 323, 343, 379, 383, 384, 402). The gradual effect of salinity increases on yield reduction has been known since White's work in 1957 (Bul. 95), and substantiated by Schekel in 1969 (Bul. 229). On the basis of some 20 years of general observation in Colorado, I estimate that total salinity in excess of the usual Denver water supply (which often exceeds 500 μmhos/cm) can represent a minimum 30% reduction in total carnation yield, and a worse effect on roses. Some general limits on individual ions were assigned by Schekel (Bul. 251, 253):

Ion	Meq/l Desired level	Meq/l Maximum allowable
Sulfate	1.0	10.0
Sodium	0	8.0
Chloride	0	2.0
Ammonium	1 to 2	Usually much higher if grower using NH_4NO_3 as major supply.
Potassium	4 to 6	8.0
Bicarbonate	0	6.0
Carbonate	0	0
Nitrate	10 to 12	Same

The seriousness of water quality in Colorado has never achieved the attention it deserves since costs of water and fertilizers share a minor part of total production cost. However, as noted with potassium chloride several years ago (Bul. 339, 343), improper use of fertilizers will have a highly significant effect on yield, which will more than offset the savings gained with cheaper water and fertilizer supplies. Maximizing yield and quality represents the best method for staying in business.

Some Errors

Because of slight changes in objectives and new students, Hartman and Holley's recommendations were modified in Bulletin 253. Recommendations on carnations for nitrate were increased to 12 meq/l. Total concentrations of the respective essential nutrients may have to be modified, because the nutrient sources utilized do not permit a physically possible solution for previous recommendations.

In Bulletin 343, which dealt with water analyses *after* fertilizer injection, the parts per million nitrate were calculated wrongly, and the value for 12 meq/l nitrate should be 744 ppm NO_3^-, not 677. Hartman and Holley also used 11-37-0 for a phosphate source instead of phosphoric acid, which also increased ammonium concentration to 2.5 meq/l, not 1.0. In Bulletin 384, the magnesium level was given as 1.0 meq/l instead of 2.0, and 3.0 meq/l calcium was increased to 6.0 meq/l. Six meq/l calcium was used in the experimental procedure, but it was wrong to attribute that recommendation to others.

Some Other Points

Even with an injection solution containing 3.0 meq/l calcium, cases have been found where calcium was unavailable, and the crop showed signs of calcium hunger, especially in inert media. Holley (Bul. 220) suggested the preplant addition of limestone, such as 5% of the medium by volume of 3/8-inch limestone gravel. This is a common procedure at the research range to ensure sufficient calcium in gravel even though the basic Hartman-Holley formula is still used. At a later date, Hanan (Bul. 305) showed that carnation tissue calcium levels were correlated with total salinity. As total solution salinity increased, tissue calcium levels declined so that during high light conditions, calcium deficiency symptoms appeared even though the grower had applied sufficient calcium and was injecting it into the watering system. In some instances, calcium uptake was found related to the acidity of the soil solution. Actual situations have been found of excessive calcium levels in gravel, and calcium injection, but deficiencies still showed up. This can be corrected by increasing the ammonium ion concentration — usually supplied from ammonium nitrate — in a nutrient solution. When taken up by the plant, the release of hydrogen ions will acidify the soil solution, making calcium more available.

A second point is the fact that bicarbonate in water supplies may be eliminated by acidifying the injection solution. The grower may use phosphoric acid, sulfuric acid or nitric acid. Since the major essential nutrient a grower must usually supply in the injection solution is nitrate, we recommend nitric acid. Nitric acid does not increase total salts as much. Sulfuric acid will add sulfate to the water, which, in Colorado waters, is usually in excess. Not as much phosphate is required by carnations or roses, so that using phosphoric acid will provide surplus levels of phosphate, as well as increasing total salts unnecessarily. In general, the bicarbonate ion is toxic to roses, as well as raising pH and interfering with iron relationships (Bul. 323). A water analysis to determine the amount of bicarbonate that is to be neutralized is required.

A third point is that, as total salinity increases, the amount of water required for irrigation increases dramatically. However, the studies by Kerr (Bul. 379, 402), show that greatest salt removal by leaching of shallow soils occurs when the total soil solution has been replaced once. After two replacements, the percentage of total salt removed becomes negligible, and certainly will not decrease below the salt level of the water being used for leaching. If one has a 1000 μmhos/cm total salinity in the water supply, that sets the minimum salt level in the soil. What the grower must do in a high salt situation is irrigate more frequently and run the soil at a higher moisture level. If there are problems with aeration and drainage, high salts will cause a "Catch-22" situation since keeping the root medium wet may result in root rot and poor growth from overwatering.

A final point is the difference in nutrition handling between soils and inert media. The buffering capacity of most soils offers a safety factor since mistakes in the nutrition program take longer to appear as a consequence of the buffering action. In gravel, this buffering action is practically nonexistent. Loss of nutrients, for example, due to an injection system breakdown, will result in visible effects on roses within one week if the medium is soilless. A similar reaction time has been noted where potassium chloride (muriate of potash) is employed as the principal potassium source in contrast to potassium nitrate. Likewise if visible effects are noted on plants growing in soils, correction of the problem will take longer.

Some Philosophy

Over the years, there has been considerable resistance to the use of Green's introduction of milliequivalents for nutritional purposes in greenhouse production — in industry and research. The terminology is different, it is metric, and it forces closer attention to detail. Once metric familiarity is learned, our graduate students tell us that calculations are greatly simplified with less chance for error. Several comments have been made that the industry has no need of a better system, and many growers desire familiar recommendations for their particular situation in English units. If an individual desires information in that fashion, then that is what should be provided by public servants when it is requested. It may not be especially stated by the asker, but that is part of the art of communication between individuals. It is not, however, for the "expert" to make an unwarranted assumption of the level of an individual's competence or desires. By implication, it insinuates that the receiver has neither the intelligence, capacity or wish to make best use of the answer. The best technology should always be available. One proceeds from that point. The principal objection to sloppy chemistry, aside from the implications it has as to the technical competence of the industry, is the fact that the situation is perpetuated in classrooms where students should receive the best and most recent advances in science and technology. To do otherwise practices a deception and slows technical advance in an era of intense economic competition.

Some General Lessons

1. A periodic water analysis (once or twice yearly) is an absolute requirement. The analysis should provide concentrations of individual ions, pH, and a reading of electrical conductivity for total salts. A hardness reading is nearly worthless. We are not drinking it, the plants are.

2. Supplies containing high bicarbonate can be acidified with nitric acid. This is a corrosive chemical, so care is required in handling it. A water analysis is necessary so that the amount of acid to be added can be calculated. One should have a care for injection machinery and piping.

3. The nutrient solution to be used is devised on the basis of the water analysis, hence the recommendations given earlier may be unrecognizable.

4. Water supplies in excess of 500 μmhos/cm electrical conductivity before injection will give difficulty and reduce growth. Water supplies in excess of 1000 μmhos/cm are, in my estimation, undesirable if automatic nutrient injection is contemplated. If 3000 μmhos/cm or more, severe problems will be observed without nutrient proportioning. At 1000 μmhos/cm or higher, serious consideration should be given to water purification such as reverse osmosis. Do not use, if at all possible, water containing 8.0 meq/l sodium, 10 meq/l sulfate or 3 meq/l chlorine. There are, of course, other good things found in water supplies such as fluoride (damage to foliage plants), boron (many southwestern water supplies but not Colorado), or heavy metals, pesticides, herbicides, *Pythium*, etc.

5. Some idea of the total water holding capacity of the soil should be available. For leaching purposes, two complete exchanges of the total moisture holding capacity, if applied uniformly to the soil surface, will be sufficient. A problem may occur with dry soils since the water will run down the sides of the soil and under the bottom of the soil layer. Pots and benches are particularly susceptible to this problem. A pre-wetting prior to actual leaching may be necessary. For field soils, more than 30% of the total water applied may have to pass through the root zone before salts are reduced significantly.