Improving Fertilizer Use Efficiency for Horticultural Crops

(Focusing on Nitrogen and Phosphorus)

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1. Types and properties of nitrogen and phosphorus fertilizers used in Florida

a. Most *nitrogen fertilizers* applied in Florida are water-soluble because these forms are plentiful and cost considerably less than slow-release or controlled-release N. Five materials make up essentially the entire suite of water-soluble N fertilizers used (Table 1). Each material has a unique set of characteristics that make it either suitable or unsuitable for particular horticultural applications. For example, the acidifying property of ammonium sulfate makes it desirable for application to acid-loving plants like blueberry. On the other hand, urea is not suitable for application to alkaline soil because much of its N will be lost by volatilization.

Table 1. Properties and uses of water soluble N fertilizers.

Material	Properties	Horticultural uses
Ammonium sulfate $(NH_4)_2SO_4$ 21% N	Highly water-soluble and leachable. Subject to N volatilization. Very acidifying. High salt index (3.25).	Turfgrass, citrus, vegetables, landscape, nursery, trees, greenhouse, deciduous and tropical fruits.
Ammonium nitrate NH_4NO_3 33% N	Highly water-soluble and leachable. Subject to volatilization. Low acidity. High salt index (2.99).	Turfgrass, citrus, vegetables, landscape, nursery, trees, greenhouse, deciduous and tropical fruits.
Urea $CO(NH_2)_2$ 46% N	Highly water-soluble and leachable. Non-ionic. Subject to volatilization. Low acidity. Low salt index (1.62).	Component of fertilizer solutions for fertigation or foliar sprays to various crops.
Potassium nitrate KNO_3 13% N	Moderately water-soluble and leachable. Increases soil pH. High salt index (5.34).	Turfgrass, vegetables. Component of fertilizer solutions for fertigation or foliar sprays to various crops.
Calcium nitrate $Ca(NO_3)_2$ 15% N	Highly water-soluble and leachable. Increases soil pH. High salt index (4.19).	Vegetables, citrus, nursery, greenhouse.

b. *Phosphorus fertilizers* applied in Florida are almost entirely water-soluble materials. When coated N-P-K materials are used, a small amount of P is applied in controlled-release form. The group of water-soluble P fertilizers used in Florida is comprised of four materials that each have unique characteristics (Table 2). They are quite versatile in their horticultural application, but there are a few instances where a particular material should not be used. For example, di-ammonium phosphate should not be applied to an alkaline soil due to volatilization of N and loss of P availability.

Table 2. Properties and uses of water soluble P fertilizers.

Material	Properties	Horticultural uses
Concentrated superphosphate $Ca(H_2PO_4)_2$ 46% P_2O_5	85-90% water-soluble P. Reaction immediately around granule is acidic (pH 1.5). Good for use on high pH soil. Low salt index (0.21).	Turfgrass, citrus, vegetables, landscape, nursery, trees, deciduous and tropical fruits.
Mono-ammonium phosphate (MAP) $NH_4\ H_2PO_4$ 18% N 48% P_2O_5	Very water-soluble and leachable. Acidic reaction. Low salt index (0.49).	Turfgrass, citrus, trees, greenhouse, deciduous and tropical fruits.
Di-ammonium phosphate (DAP) $(NH_4)_2HPO_4$ 11% N 46% P_2O_5	Very water-soluble and leachable. Subject to volatilization on high pH soils. Initial basic reaction, then acidifying. Low salt index (0.64).	Turfgrass, landscape, citrus, trees, greenhouse, deciduous and tropical fruits.
Ammonium polyphosphate 10% N 34% P_2O_5	Liquid N and P fertilizer. Slightly acidic reaction.	Component of fertilizer solutions for fertigation or foliar sprays to various crops.

2. Slow and controlled-release fertilizers

a. *Properties and characteristics*. In Florida, high volume use of controlled-release fertilizers (CRF) in horticultural applications is limited to turfgrass, greenhouse, nursery, and landscape settings due to high cost compared with water-soluble fertilizers (WSF). Smaller amounts of CRF are used in citrus re-plant situations and other specialty horticulture. For example, tomato growers often include some slow-release N in fertilizer blends applied under plastic mulch.

Mode of release for slow and controlled-release N fertilizers:

- Coated fertilizer: Water-soluble N (either alone or in combination with other nutrients) is surrounded by an impermeable or semi-permeable coating. Nutrients are released by diffusion through the coating or following degradation of the coating. Examples include sulfur-coated urea (SCU), Osmocote®, Nutricote®, and Polyon®.
- Non-coated fertilizer: Materials of limited water solubility release plant-available N as they decompose, either chemically or microbially. Examples include isobutylidene diurea (IBDU), methylene urea (MU), and ureaform (UF).

In all cases, moisture and temperature play a significant role in determining how quickly N and other nutrients are released. Therefore, it is important for the user to understand how a particular material works and to know its designed release rate prior to applying it in a horticultural situation.

Properties of common slow and controlled-release fertilizers used in Florida are described in Table 3.

Table 3. Properties of common slow and controlled-release fertilizers used in Florida horticultural applications.

Product	Nutrients	Properties
Ureaform (UF) 38% N	N	Water-insoluble organic compound. Biological N release influenced by soil temperature. Roughly a 90-day release period.
Methylene urea (MU) (e.g. Nutralene®) 40% N	N	Water-insoluble organic compound. Biological N release, more rapid than UF. Not as adversely affected by cool temperatures.
UF solution 28% N (CoRon®)	N	Non-modified and amine-modified polymethylene urea. N release rate depends on microbial action.
IBDU 31% N	N	N released by hydrolysis (molecule converts to urea). Release relatively unaffected by temperature, so cool season response is excellent. Release is affected by particle size (smaller = faster). Roughly a 60-day release period.
Sulfur-coated urea (SCU) 32 – 38% N	N, S	N release depends on thickness of S coating, biological activity, temperature, and soil pH. Cool season response is erratic. The S coating can be fragile; if it cracks, the slow-release property is lost. Roughly a 60-day release period.
Osmocote®	N, P, K plus secondary and micro-nutrients	Soluble fertilizer core coated with a polymer. Nutrient release pattern varies with coating thickness. Commercial products are a blend of different coating thicknesses. Nutrient release is by diffusion through the coating. Release is affected by temperature. Designed release rates vary from 5 to 16 months.
Polyon®	N, P, K, S	Polyurethane-coated urea. N is released by osmotic diffusion. Release rate is influenced by coating thickness and temperature. Coating is abrasion-resistant.
Nutricote®	N, P, K plus secondary and micro-nutrients	Soluble fertilizer coated with polyolefin. Nutrient release is controlled by coating composition, not thickness. Continuous moisture is necessary for nutrient release. Release period varies from 40 to 540 days, depending on coating properties.
Polymer/Sulfur-coated fertilizers (PCU; PCSCU)	N	Primary coating of sulfur with a secondary polymer coat. Use of sulfur as a coating material decreases cost of production. Coating is abrasion-resistant. Nutrients are released by a combination of diffusion and capillary action. Release is less temperature sensitive than straight polymer-coated fertilizers.

b. *Rates used compared with standard (water-soluble) materials.*

Numerous Florida studies have measured the horticultural performance, and in some cases leaching, of CRFs compared with WSF. Although most experiments focused on evaluating a wide variety of CRF sources, some were structured to allow the determination of a rate x source interaction (Table 4).

Table 4. Summary of studies comparing CRF with water-soluble fertilizer (WSF) where it was possible to determine a rate x source interaction.

Study location and year of report	Crop	CRFs tested vs. WSF	Did a lower rate of CRF perform as well or better than a higher rate of WSF?
Lake Alfred, 1992	Non-bearing citrus trees	MU, SCU, IBDU, Osmocote®	**Yes**. In a 2-year period, CRF applied at a 50% rate performed equally well compared with WSF applied at the recommended (100%) rate.
Gainesville, 1992	Bell pepper	MU, IBDU, Multicote®, Nutricote®	**No**. In a single-year study, there was no interaction between fertilizer source and rate with respect to pepper yield.
Gainesville, 1993	Bermudagrass and ryegrass	IBDU, Coated WSN	Single-season study. **No** for turf growth. **Yes** for turf visual quality; same visual quality from half-rate of CRF compared with full rate of WSF.
Bradenton, 1993	Tomato	PCU	**No**. In a single-year study, CRF was less effective than WSF.
Polk Co., 1993	Newly-planted citrus trees	Resin-coated (Meister®)	**Yes**. In a 2-year period, CRF applied at a 50% rate or less performed equally well compared with WSF applied at the recommended (100%) rate.
St. Lucie Co., 1993	Mature citrus trees	Osmocote®	**Yes**. In a 4-year period, CRF applied at 15% and 25% rates performed equally well compared with WSF applied at the recommended (100%) rate.
LaBelle, 1993	Newly-planted citrus trees	IBDU, MU	**No**. In a 4-year period, there was no interaction between fertilizer source and rate with respect to tree growth, fruit yield, or juice quality.
Gainesville, 1994	Bermudagrass	IBDU, PCSCU	Single-season study. **No** for both turf growth and visual quality.
Gainesville, Lutz, and Vero Beach, 1995	Newly-planted citrus trees	PCU, IBDU, Osmocote®	**Yes**. In a 4-year period, all CRFs applied at a 20% rate performed equally well compared with WSF applied at the recommended (100%) rate.
Gainesville, 1995	Warm and cool season turfgrasses	UF, MU, IBDU, Coated WSF	Single-season study. **No** for both turf growth and visual quality.
Gainesville, 1996	Ryegrass	IBDU, Coated WSF	Single-season study. **No** for turf growth. **Yes** for turf visual quality; same visual quality from half-rate of CRF compared with full rate of WSF.
Gainesville, 1996	Bermudagrass	IBDU, Coated ammonium sulfate	Single-season study. **No** for both turf growth and visual quality.
Highlands Co.,	Mature citrus	PCU	**No**. In a 3-year period, there was no interaction between fertilizer source and rate with respect to

1998	trees		orange yield.
Immokalee, 1999	Newly-planted citrus trees	Escote®, Meister®, Osmocote®, Nutricote®, Prokote®	**Yes**. In a 6-year period, Osmocote® applied at a 50% rate performed equally well compared with WSF applied at the recommended (100%) rate.
Hastings, 2003	Potato	PCU, PCSCU, unknown CRF	**Yes**. In a single-year study, CRF applied at 50% and 75% rates performed equally well compared with WSF applied at the recommended (100%) rate.
LaBelle, 2006	Young bearing citrus trees	IBDU, MU	**No**. In a 4-year period, there was no interaction between fertilizer source and rate with respect to total soluble solids yield.

A typical question that a producer considering the use of CRF asks is: "Can I apply a lower fertilizer rate when using CRF compared with my conventional WSF program and get the same response?" Table 4 suggests there is no definitive answer. Of the 16 experiments summarized, six showed that a lower rate of CRF performed as well or better than a higher rate of WSF, eight showed no rate advantage to CRF, and two showed mixed results depending on the measured response. Of the six "yes" answers, five involved citrus trees and one involved vegetables. Of the eight "no" answers, three involved citrus, three involved turfgrass, and two involved vegetables.

c. The goal in *timing CRF application* is to match the initial portion of the "release curve" with the beginning of the growing season. For example:
   - Newly-planted citrus trees: At planting.
   - Established citrus trees: Late winter/early spring, prior to the first spring vegetative flush and bloom.
   - Turfgrass and landscape: Late winter/early spring in north Florida; any time in south Florida.
   - Vegetables: Pre-plant, beneath the plastic mulch if applicable.
   - Greenhouse and nursery: Incorporate in potting media or top-dress potted plants.

d. *Placement of CRF* (e.g., surface vs. incorporated) is important in improving efficiency and decreasing leaching for containerized plant production. In a CRF placement study, surface application of Osmocote® to sweet viburnum did not affect plant growth compared with incorporation. However, N and P leaching losses were reduced 16 and 25%, respectively, when the CRF was surface-applied.

   CRFs undergoing evaluation for long-term use on citrus trees were applied to the soil surface even if the manufacturer's instructions stated that the material should be incorporated. In all cases, surface application did not detrimentally affect CRF performance, probably because they were applied within the wetted pattern of the microirrigation system that maintained a continuous moist environment on the grove floor.

e. *Plant response to* CRF depends on how well release characteristics (release curve) match plant needs. It is important for a producer to be familiar with the nutrient release pattern of a CRF before using it. Studies evaluating CRF use in vegetable production have emphasized how a crop can suffer if nutrient release is not fast enough at the beginning of the growing season.

Fig. 1 shows an example of a CRF release curve that is well-matched to plant needs. Citriblen® fertilizer is formulated for use in mature citrus groves, where recommendations suggest that two-thirds of the N should be released within 110 days after applying in the spring.

f. *Nitrogen leaching* from field-applied CRF is minimal because by design, these materials release water-soluble N to the soil at a slow rate. Non-released N either remains in an insoluble form or is protected from dissolution by a coating, so it cannot leach all at once.

Leaching from CRF has been measured in laboratory simulations with no plants (Table 5), measured in the field beneath turfgrass (Table 6), and estimated in a central Florida ridge citrus grove (Table 7). In all cases, N leaching from water-soluble N fertilizer was significantly greater than leaching from CRF.

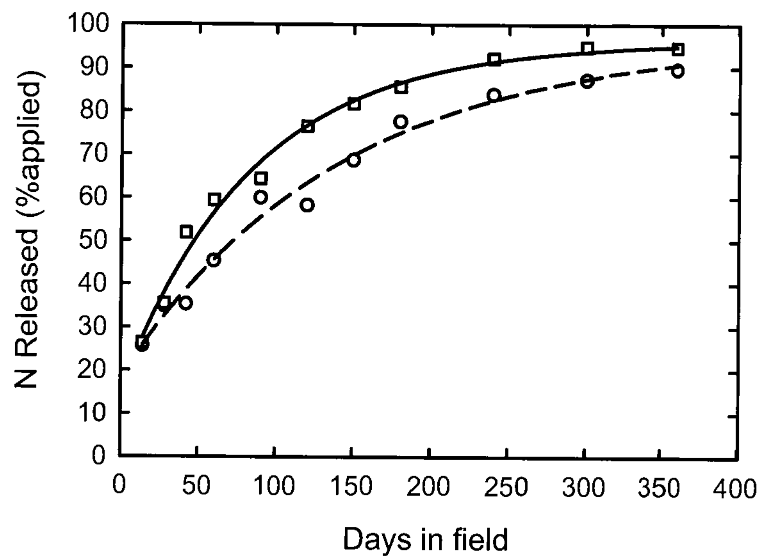

Fig. 1. Nitrogen release pattern of Citriblen® in south (top line) and central (bottom line) Florida.

Table 5. Leaching of water-soluble and controlled-release N fertilizer following 40 inches of simulated rainfall in 30 days.

N source		Percentage of applied N that leached	
		Candler sand	Wabasso sand
Water-soluble	Ammonium nitrate	100	88
CRF	IBDU	32	27
CRF	Meister® plastic coated	12	12

Table 6. Leaching of water-soluble and controlled-release N 125 days after applying 2 lbs N/1000 square ft to ryegrass.

	N source	Percentage of applied N that leached[z]
Water-soluble	Ammonium sulfate	12.8 a
Water-soluble	Urea-Ammonium nitrate	8.1 b
CRF	CoRon®	7.2 b
CRF	Nutralene® (methylene urea)	2.9 c
CRF	Polyon®	2.8 c
CRF	Sulfur-coated urea	2.8 c
CRF	IBDU	1.1 d
CRF	Nitroform® (ureaform)	0.4 e

[z] Values followed by the same letter are not significantly different from each other.

Table 7. Estimated N leached below a central Florida ridge citrus grove root zone.

N rate	Dry soluble fertilizer	Fertigation	CRF
lbs/acre	------------------------ lbs N/acre/year ------------------------		
50	---	---	0.8
100	11.1	16.3	2.9
150	11.8	21.5	7.1
200	12.2	27.1	---
250	19.0	31.3	---

Nitrogen leaching from containerized plant production has also been measured. In one experiment, plant growth substrate influenced the relative amount of fertilizer N that leached (Table 8). Less nitrate leached from CRF compared with WSF when plants were grown in pine bark-peat-sand media. When the media was sandy field soil, nitrate leaching did not differ between fertilizer types. Phosphorus leaching was always lower from CRF regardless of potting substrate type. Plant growth was as good or better with CRF compared with WSF.

Table 8. Container-grown foliage plant size and relative amount of N and P leached 6 months after CRF or WSF fertilizer application to two potting substrates.

Fertilization method	Spathiphyllum plant size		Percentage of total N applied that leached as NO_3^-		Percentage of total P applied that leached as PO_4^{3-}	
	Pine bark-peat-sand media	Sandy field soil[z]	Pine bark-peat-sand media[z]	Sandy field soil	Pine bark-peat-sand media[z]	Sandy field soil[z]
	------- dry weight (g) -------		------------- % -------------		------------- % -------------	
Liquid WSF	30	22 b	48 b	47	28 a	17 b
Dry granular WSF	28	18 c	54 a	46	23 b	22 a
Lightly-coated CRF	31	24 ab	29 d	44	12 d	11 c
Heavily-coated CRF	33	27 a	35 c	45	18 c	16 b

[z] Values followed by the same letter are not significantly different from each other.

g. Effects of temperature and moisture on release rates.
   i. Temperature – In most cases, as temperature increases, nutrient release from CRF increases. However, the temperature-release curve relationship has not been well-defined in a quantitative way for many of the CRFs used in Florida.
   ii. Moisture – Surface-applied CRF releases nutrients more slowly than incorporated CRF due to intermittent wetting and drying. For continuous nutrient release, CRF particles need to be continuously moist, but they do not require complete immersion in free water.

3. Fertigation

a. *Nutrient use-efficiency (NUE),* defined as the ratio of the amount of nutrient taken up by the target plant to the amount applied, can be increased by substituting fertigation for pre-plant WSF application in vegetable production. When bell pepper yield was used an indicator, N use-efficiency increased as the proportion of N applied via fertigation increased (Table 9). Increased yield implies more N in the fruit per unit area, hence less potential leaching.

b. Citrus trees do not appear to be sensitive to *fertigation application frequency.* This characteristic allows wide flexibility when setting up a grove fertigation schedule. For example, the 1-year growth response of newly-planted citrus trees in Gainesville did not differ when fertigated 30, 10, or 5 times at the same total N rate. Growth observed with fertigation was not different from that observed with dry granular fertilizer applied five times per year.

   Fertigation frequency also was not a factor when applied to 6-year-old lysimeter-grown trees in Lake Alfred (Table 10). Neither N uptake efficiency nor the relative amount of applied N that leached were significantly different when comparing ~80 fertigations per year with ~12 per year.

Table 9. Bell pepper marketable yield at four pre-plant/fertigation N fertilizer combinations applied under plastic mulch to Arredondo fine sand in Gainesville (1995).

Fertilizer N application method			
Relative amount of N applied pre-plant	Relative amount of N applied by fertigation	Total fancy pepper yield	Total marketable pepper yield
		-------------------- tons/acre --------------------	
0	100	4.2	9.1
30	70	4.4	9.5
70	30	3.8	8.3
100	0	2.9	6.6
P-value		0.0531	0.0006

Table 10. Influence of the number of fertigations applied to 6-year-old orange trees growing in lysimeter tanks on the relative amount of N leached and N uptake efficiency.

Year	Fertigation treatment	Fertigations per year	Relative amount of applied N that leached	N uptake efficiency[z]
			%	%
1999	With every irrigation	76	51	30
	Weekly	36	58	27
	Monthly	11	56	24
2000	With every irrigation	81	46	42
	Weekly	38	62	28
	Monthly	14	53	35

[z] Amount of N taken up by the citrus trees divided by the amount of N applied.

Fertigation frequency for vegetables can vary from daily application to one fertigation per week. No advantage to daily vs. weekly fertigation has been observed with proper irrigation management. Nitrogen fertilizer application is most precise if rates are determined by crop growth and resulting nutrient demand. Nitrogen rates begin at about 0.5 lbs/acre/day during the early part of the season and increase to around 2 lbs/acre/day at peak demand.

c. Horticultural *plant response* to fertigation is as good as or better than the response observed with well-managed dry soluble fertilization. In both cases, irrigation (and sometimes drainage) water management is critical for success.

d. *Nitrogen leaching* following fertigation can be minimized if the crop is not over-irrigated. It cannot be emphasized enough how important irrigation duration is when fertigating. Although fertigation is sometimes referred to as "spoon feeding," in this case the "food" is water-soluble plant nutrients that can easily be driven beneath the plant root zone if too much water follows the fertilizer pulse. It is true that fertigation prevents a large mass of nutrients from being leached in a single day (as could occur when heavy rain follows a dry fertilizer application), but leaching can still occur in smaller increments if irrigation management is poor.

An interesting result of the study summarized in Table 10 was that even in a lysimeter with carefully-controlled irrigation and a confined root system, about half of the N applied via fertigation leached past the root zone.

Table 7 shows an example that is contrary to the principle outlined above. Irrigation scheduling in the test citrus grove was optimal, yet more N leached in the fertigation treatment compared with dry soluble fertilizer applications. The authors of this study explained that more N leaching occurred with fertigation "purely because of unexpected prolonged irrigation or unexpected high rainfall following certain fertigation events in both years."

4. Foliar fertilization

a. *Citrus*. The amount of plant nutrients that can be taken up through the leaves of a citrus tree is very small. However, there are special cases where foliar application of N and/or P is justified. It must be recognized that a positive response may be due to additional effects of the materials on tree physiology beyond simple enhancement of tree nutrition.

Nitrogen

Forms of urea are available that can be readily absorbed by citrus leaves. Foliar urea sprays applied during the winter have enhanced the number of flowers and yield of Valencia oranges. After cool temperatures or drought stress have occurred, applying 50 to 60 lbs of spray grade urea per acre can enhance flower bud induction and may increase fruit yield. Maximum penetration of urea into citrus leaves occurs within 12 to 24 hours after spray application. Optimum conditions for foliar uptake include air temperature between 77 and 88° F, high relative humidity, and spray solution with a pH between 7 and 8 to prevent urea breakdown.

Under favorable environmental conditions, roughly half of foliar-applied urea penetrates the leaves, while most of the other half is lost through volatilization. The rate of foliar-applied N should be considered as part of the total annual N rate applied to the grove. For example, a foliar spray of 50 lbs urea/acre applies 23 lbs N/acre. If the fertilization plan calls for a total of 180 lbs N/acre/year, only 157 lbs N/acre should be included in the soil-applied fertilizer program.

In Florida citrus production areas where groundwater nitrate contamination exists or is seen as a potential problem, urea sprays should be evaluated to provide a portion of the tree N requirements, especially during the summer months when leaching potential is the greatest.

Phosphorus

Citrus leaves are extremely impervious to phosphate (PO_4^{3-}). Conversely, phosphite (PO_3^{3-}) is more readily absorbed into plant tissue, and once inside the plant it remains stable. Phosphite does not readily convert to phosphate in the plant so the nutritional value of absorbed PO_3^{3-} is uncertain. However, phosphite is officially recognized by FDACS as a source of P for crops.

In Florida, a pre-bloom foliar application of 2.6 quarts of 28% P_2O_5 as potassium phosphite per acre to Valencia oranges significantly increased flower number, fruit yield, and total soluble solids yield compared with an untreated control. These results suggest that the effect of phosphite was not due to the molecule's fungicidal attributes, but to other growth-stimulating properties.

b. *Vegetables.* Foliar applications of N and P are not recommended for vegetable production because leaves cannot absorb sufficient quantities to correct a deficiency, and leaf burn is likely if this is attempted.

5. Costs of materials and application

a. *Citrus.* Although coated fertilizers performed very well in a 6-year trial comparing them with a standard WSF program (1991-96), they would not have been economically feasible for commercial production during that time. The CRF materials evaluated would have cost three to four times as much to use as WSF, even when the lower application cost was factored in (Table 11). Extra yield obtained by using CRF did not nearly make up for the higher fertilizer cost.

Table 11. Costs to fertilize young Valencia orange trees for a 6-year period compared with cumulative yields and gross returns.

Fertilizer	6-yr fertilization cost	Cumulative yield	Gross return
	$/tree	lbs solids/tree	$/tree
Prokote®	15.49	27.7	28.90
Sierra®	19.20	27.0	28.25
Nutricote®	19.85	26.5	27.47
Meister®	15.81	25.8	26.41
Escote®	14.90	24.9	25.98
Water-soluble	5.06	24.2	25.40

b. *Vegetables.* A potato production study determined that the cost of a water-soluble N fertilization program in most years would fall between $38 and $63 per acre. Estimated CRF program cost would be approximately $8 to $79 more than the most expensive soluble N cost.

This extra cost could be offset by reduced application cost and/or providing cost-share for the use of CRF.

6. How irrigation affects fertilizer use efficiency

Fertilizer use efficiency of container-grown ornamental production was improved by changing the irrigation and/or fertilization methods. One change involved the conversion of overhead irrigation to microirrigation or capillary mat/wick irrigation. The other change involved the use of CRF (Osmocote®, Nutricote®, Multicote®, and Polyon®) with overhead irrigation. During a 4 year period, the growth index of Spathiphyllum was about the same regardless of CRF source. However, the nitrate-N concentration in the groundwater 4 ft below the ground surface of the shadehouse decreased as a result of using CRF (Fig. 2).

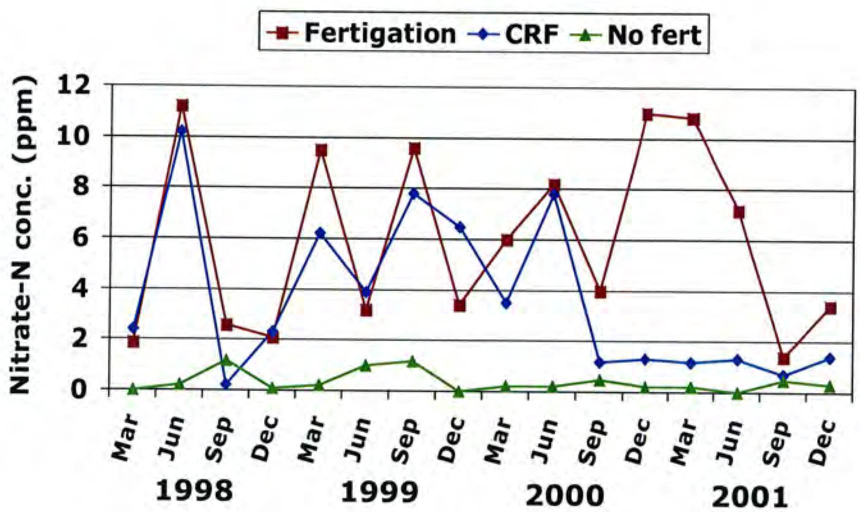

Fig. 2. Effect of N fertilizer type and application method on ground water nitrate concentration beneath ornamental plant production.

In another study involving containerized production of Osmocote®-fertilized sweet viburnum, excessive irrigation (double the required rate) decreased plant growth, increased runoff volume from the nursery, increased N loss in runoff by 21 to 34%, and increased P loss in runoff by 28 to 38%.

7. Opportunities to improve fertilizer use efficiency

Best Management Practices (BMPs). Most nutrient BMPs are simple, common-sense, "good housekeeping" practices that producers already use. In abbreviated form, they involve:

- Educating and training field operators about how to manage fertilizer.
- Developing a nutrient management plan.
- Using appropriate application equipment.
- Properly calibrating and maintaining application equipment.
- Applying fertilizers to target sites.

- Avoiding high risk fertilizer applications (such as during the rainy season).
- Splitting fertilizer applications throughout the growing season.
- Trying to wet only the root zone when irrigating.
- Adding organic matter to the soil whenever possible.
- Using appropriate fertilizer sources and formulations.
- Using precision nutrient application where appropriate.

8. Focus for future research efforts

a. Develop a short-term laboratory procedure that can verify the nutrient release period claimed on CRF labels.

b. Evaluate plant response and nutrient leaching characteristics of CRF materials applied in the field and greenhouse.

c. Conduct a comprehensive economic study of CRF use including material cost, plant response (yield and quality), and environmental benefits

d. Improve irrigation scheduling techniques. For example, advance capabilities and performance of automated irrigation systems for better accuracy.

e. Continue development of new application technology for precision nutrient application.

f. Variable rate irrigation – Link variable rate fertilization with fertigation.

9. References

Albregts, E. E., and C. K. Chandler. 1993. Slow-release fertilizer rates for strawberry fruit production. Proc. Fla. State Hort. Soc. 106:187-189.

Albrigo, L. Gene. 1999. Effects of foliar applications of urea or Nutriphite on flowering and yields of Valencia orange trees. Proc. Fla. State Hort. Soc. 112:1-4.

Alva, A. K., and D. P. H. Tucker. 1993. Evaluation of a resin coated nitrogen fertilizer for young citrus trees on a deep sand. Proc. Fla. State Hort. Soc. 106:4-8.

Alva, A. K., and S. Paramasivam. 1998. Nitrogen management for high yield and quality of citrus in sandy soils. Soil Sci. Soc. Am. J. 62;1335-1342.

Boman, B. J. 1993. A comparison of controlled-release to conventional fertilizer on mature 'Marsh' grapefruit. Proc. Fla. State Hort. Soc. 106:1-4.

Broschat, T. K. 1995. Nitrate, phosphate, and potassium leaching from container-grown plants fertilized by several methods. HortScience 30:74-77.

Broschat, T. K. 2005. Rates of ammonium-nitrogen, nitrate-nitrogen, phosphorus, and potassium from two controlled-release fertilizers under different substrate environments. HortTechnology 15:332-335.

Cisar, J. L., G. H. Snyder, and K. E. Williams. 1995. The effect of controlled-release fertilizers on Tifgreen bermudagrass. p. 189-200. *In* J. L. Cisar (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Csizinszky, A. A. 1989. Effect of controlled (slow) release nitrogen sources on tomato, Lycopersicon esculentum Mill. Cv. Solar set. Proc. Fla. State Hort. Soc. 102:348-351.

Csizinszky, A. A., C. D. Stanley, and G. A. Clark. 1993. Evaluation of controlled-release urea for fresh market tomato. Proc. Fla. State Hort. Soc. 106:183-187.

Davies, F. S., M. Tignor, and L. A. Mathers. 1996. Irrigation and fertilization of young interset Hamlin orange trees in Florida. Proc. Fla. State Hort. Soc. 109:77-80.

Ferguson, J. J., and F. S. Davies. 1995. Fertilization of young citrus trees with controlled release fertilizers. Proc. Fla. State. Hort. Soc. 108:156-160.

Medina, L. C., T. A. Obreza, J. B. Sartain, and R. E. Rouse. 2008. Nitrogen release patterns of a mixed controlled-release fertilizer and its components. HortTechnology 18:xx-xx (in press).

Million, J., T. Yeager, and J. Albano. 2007. Effects of container spacing practice and fertilizer placement on runoff from overhead-irrigated sweet viburnum. J. Environ. Hort. 25:61-72.

Million, J., T. Yeager, and J. Albano. 2007. Consequences of excessive overhead irrigation on runoff during container production of sweet viburnum. J. Environ. Hort. 25:117-125.

Obreza, T. A. 1993. Program fertilization for establishment of orange trees. J. Prod. Agric. 6:546-552.

Obreza, T. A., R. E. Rouse, and J. B. Sherrod. 1999. Economics of controlled-release fertilizer use on young citrus trees. J. Prod. Agric. 12:69-73.

Obreza, T. A., and R. E. Rouse. 2006. Long-term response of 'Hamlin' orange trees to controlled-release nitrogen fertilizers. HortScience 41:423-426.

Paramasivam, S., and A. K. Alva. Leaching of nitrogen forms from controlled-release nitrogen fertilizers. Commun. Soil Sci. Plant Anal. 28(17&18):1663-1674.

Saha, S. K., L. E. Trenholm, and J. B. Unruh. 2007. Effect of fertilizer source on nitrate leaching and St. Augustinegrass turfgrass quality. HortScience 42:1478-1481.

Sartain, J. B. 1992. Relative nitrogen leaching losses from selected slow-release nitrogen sources. P. 131-136. *In* T. E. Freeman (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Sartain, J. B. 1993. Comparative growth rate and quality response of bermudagrass and ryegrass to various sources of slow-release N fertilizer. p. 77-81. *In* J. L. Cisar and J. J. Haydu (eds.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Sartain, J. B. 1994. Bermudagrass growth and quality response to poly-S materials. p. 51-63. *In* A. E. Dudeck (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Sartain, J. B. 1994. Comparative evaluation of nutrient sources on St. Augustinegrass. p. 78-74. *In* A. E. Dudeck (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Sartain, J. B. 1994. Controlled-release nitrogen sources for cool and warm season grasses. p. 95-103. *In* A. E. Dudeck (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Sartain, J. B. 1994. Effects of Multicote materials on ryegrass growth and quality. p. 110-115. *In* A. E. Dudeck (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Sartain, J. B. 1995. St. Augustinegrass growth response to controlled-release blends. p. 57-70. *In* J. L. Cisar (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Sartain, J. B. 1995. Warm and cool season turfgrass response to controlled-release nitrogen. p. 165-174. *In* J. L. Cisar (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Sartain, J. B. 1996. Response of ryegrass to controlled-release nitrogen sources. p. 190-192. *In* J. L. Cisar (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Sartain, J. B. 1996. Response of bermudagrass to controlled-release nitrogen sources. p. 212-214. *In* J. L. Cisar (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Sartain, J. B., and J. K. Kruse. 2001. Selected fertilizers used in turfgrass fertilization. Univ. of Florida-IFAS, Soil and Water Science Dept. Cir. 1262.

Shaw, N. L., G. J. Hochmuth, and E. A. Hanlon. 1996. N fertilization management for drip-irrigated bell pepper (*Capsicum annuum* L.). Proc. Fla. State Hort. Soc. 109:136-141.

Simonne, E., and C. M. Hutchinson. 2005. Controlled-release fertilizers for vegetable production in the era of best management practices: Teaching new tricks to an old dog. HortTechnology 15:36-46.

Syvertsen, J. P., and J. L. Jifon. 2001. Frequent fertigation does not affect citrus tree growth, fruit yield, nitrogen uptake, and leaching losses. Proc. Fla. State Hort. Soc. 114:88-93.

Varshovi, A. A., and J. B. Sartain. 1993. Growth, N uptake, and leaching characteristics of polymer-coated urea and ammonium sulfate applied to bermudagrass. p. 59-67. *In* J. L. Cisar and J. J. Haydu (eds.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Varshovi, A. A., and J. B. Sartain. 1996. Nitrogen uptake of Tifway bermudagrass in response to polymer-coated ammonium sulfate. p. 149-152. *In* J. L. Cisar (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Varshovi, A. A., and J. B. Sartain. 1996. Comparative growth of Tifgreen bermudagrass in response to golf greens grade polymer-coated ammonium sulfate and urea. p. 153-159. *In* J. L. Cisar (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Varshovi, A. A., and J. B. Sartain. 1996. Nitrogen uptake of Tifgreen bermudagrass in response to golf greens grade polymer-coated ammonium sulfate. p. 171-174. *In* J. L. Cisar (ed.) Turfgrass research in Florida. Univ. of Florida, Gainesville, FL.

Wang, F. L., and A. K. Alva. Leaching of nitrogen from slow-release urea sources in sandy soils. Soil Sci. Soc. Am. J. 60:1454-1458.

Willis, L. E., F. S. Davies, and D. A. Graetz. 1991. Fertigation and growth of young 'Hamlin' orange trees in Florida. HortScience 26:106-109.

Yeager, T. H., and R. W. Henley. 2004. Irrigation and fertilization for minimal environmental impact. p. 233-240. *In* L. Bertschinger and J. D. Anderson (eds.) Proc. XXVI Int. Hort. Conf. – Sustainability of Horticultural Systems. Acta. Hort. 638.

Zekri, M. and R. C. J. Koo. Use of controlled-release fertilizers for young citrus trees. Scientia Horticulturae 49:233-241.