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A Summary of N, P, and K Research with Tomato in Florida[1]

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Harvest of fresh market tomatoes in Florida for the 1996-1997 season resulted in 54,750,000 cartons (25 lb/carton) from 37,300 harvested acres (37,500 planted acres). Crop value was $462,526,000 (Fl. Dept. of Agr. and Cons. Serv., 1998). Most of the tomatoes produced in Florida were grown in the spring season (70%) with the remainder grown in the fall. Heaviest tomato production occurs in the Southwest: Bonita Springs, Immokalee, Naples, and the Palmetto-Ruskin areas produce 70% of the state s tomatoes.

State agricultural chemical usage including fertilizer use is surveyed periodically by a USDA-administered program and results are published (Fla. Agr. Stat. Serv., 1995). During the 1994 tomato crop season, N (nitrogen), P_2O_5, and K_2O were applied at an average of 310-200-540 lb/acre, rates that exceeded current IFAS nutrient recommendations for this crop (Hochmuth and Hanlon, 1995). Maximum recommended nutrient rates are 175-150-225 lb/acre N, P_2O_5, K_2O with phosphorus (P) and potassium (K) rates adjusted downward or eliminated if soils can supply some or all of these nutrients as determined by soil testing. Application of plant nutrients in excess of crop needs poses a negative environmental risk and reduces profitability.

Tomato fertilization research has been conducted in Florida for more than forty years. During this time many changes have occurred in tomato production practices including changes in cultivars, and the introduction of new cultural systems such as polyethylene mulch, drip irrigation, and the use of complete soil fumigants. The purpose of this publication is to summarize tomato fertilization research leading to current University of Florida recommendations for tomato fertilization and to summarize needs for refinement of recommendations and for continued research. Since nutrient and water management are linked, fertilization research will be summarized by irrigation method.

Data Summary Method

To evaluate tomato yield response to variable rates of fertilizer, a procedure was needed to standardize the numerous units used for quantifying statewide yield results such as bushels, cartons, boxes, or tons/acre. In addition, vegetable yields can

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vary slightly depending on season, cultivar, and location in the state. Relative yield (RY), a calculated percentage, was chosen as the unit to express tomato yield responses to fertilization. The highest yield for each fertilizer experiment was assigned a 100% value and other yields were expressed as a percentage of the highest yield. The actual yield in original units (25-lb cartons/acre) is presented for the treatment corresponding to 100% RY. The RYs were plotted against rates of nutrient to determine how tomato yields responded to fertilizer in Florida. The RY presentation allowed data from a variety of experiments to be included in the graphical summary of yield responses to fertilization. For most studies, RYs of 95 to 100% were not significantly different.

Fertilizer rates are expressed on a per-acre basis (amount of fertilizer used on a crop growing in an area of 43,560 sq ft). Changes in bed spacing often lead to needed changes in fertilizer amounts. For example, to maintain the same amount of fertilizer in the bed for a crop on 6-foot bed spacing as a crop with 4-foot bed spacing would mean an increase by a factor of 1.5, in the "per acre" rate of fertilizer for the crop growing in beds spaced 4-foot on center. The important aspect is to have the same amount of fertilizer per linear bed foot. This linear bed foot system is used by the University of Florida Extension Soil Testing Laboratory to express fertilizer rates. The concept is explained by Hanlon and Hochmuth (1989) and by Hochmuth (1996). Fertilizer rate expressions used in this summary and its figures are those rates presented by the various authors in their research papers. Most authors expressed rates on a per-acre basis, irrespective of variations in bed spacings among reports or experiments. Authors of a few reports chose to use the linear bed foot system to standardize fertilizer rate expressions across experiments and planting patterns. We will attempt to specify planting patterns and fertilizer rates for each experiment as far as we can determine from each report.

Nitrogen Mixed Fertilizer Trials

Experimentation with tomato fertilization included numerous studies where mixed N-P-K fertilizers were used. Yield results from three of these studies are presented here as responses to rate changes of N fertilizer since N is the most limiting major nutrient in sandy soils. Yields from these mixed fertilizer studies, however, were not graphed with experiments where N rate was increased and P and K were applied at uniform rates for all treatments (Fig. 1).

Fertilizer rate studies were a secondary aspect of two Immokalee experiments conducted in the fall of 1970 and spring of 1971 (Everett, 1971). Increased use of polyethylene mulch on several thousand south Florida tomato-production acres resulted in disposal problems estimated at \$50 to \$70 per acre. Residual polyethylene in the field was caught up in tillage equipment, interfered with seeding and transplanting operations. These problems aroused interest in biodegradable paper and polyethylene-coated paper mulches. Tan or black paper mulches (impregnated with a fungicide to retard decomposition) were uncoated or coated with 0.25 mil of polyethylene coating on one or both sides. Single side coated mulches were applied either coated side up to the sun or down on the soil. Yield results from tomatoes mulched with these biodegradable mulching materials were compared to yields from plants mulched with 1.5 mil of black polyethylene. Yields were also compared for plants fertilized with N-P_2O_5-K_2O fertilizer formulations of 130-72-157 (low), 220-72-261 (medium), or 310-72-364 (high). All treatments received 40 lb/acre N from a 5-8-8, N-P_2O_5-K_2O, fertilizer placed 3 inches to each side of the bed center and 3 inches deep. A second application of an 18-0-25, N-P_2O_5-K_2O, fertilizer was applied 9 inches to each side of bed center at rates of 500, 1,000, or 1,500 lb/acre. This single fertilizer side-dress application was divided into two side-dress applications for the unmulched beds. Un-staked, subsurface-irrigated plants were grown for one to three harvests. Row or water-furrow spacing was not indicated.

Mulch type and fertilizer rate did not interact significantly for either experiment. Yields did not respond to increased fertilization in these experiments where the author noted a limited, 1 to 3 pick, harvest season reduced the demand for fertilizer. Yields averaged 1,227 cartons/acre over all fertilizer and mulch treatments in fall 1970. In the spring, 1971 season, yields fell slightly between the

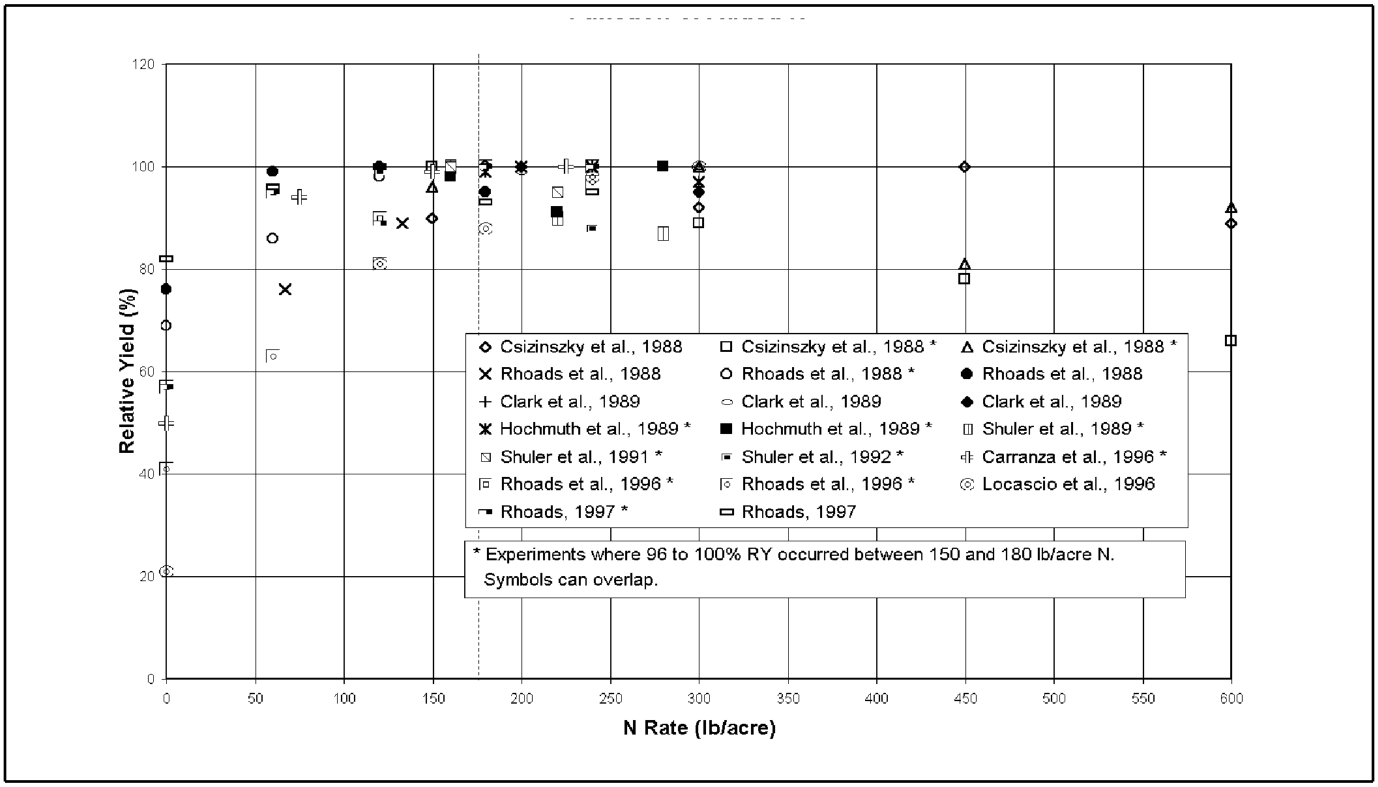

Figure 1. Relative yield of tomatoes for experiments, years, and seasons as a function of added N.

medium and high fertilizer treatments, 220 to 310 lb/acre N, from 1,664 to 1,536 cartons/acre (significant at 5% probability). Yields were best from plants mulched with uncoated tan paper (1,464 cartons/acre) or black paper (1,376 cartons/acre) in the fall, 1970. Yields from plants with all other mulch treatments were not significantly greater than yields from unmulched plants (1,184 cartons/acre). Drought conditions and low temperatures in spring 1971 accentuated the benefits of mulch. Yields were significantly better (1% probability) from all mulched plants, regardless of mulch type, compared to unmulched plants. Mulched plants produced 400 to 856 cartons/acre more tomatoes than the unmulched plants with higher yields from black mulches than from tan mulches. The highest yields in this dry season resulted from tomato plants mulched with black paper (polyethylene side to the soil), 1,920 cartons/acre compared to yields from unmulched plants, 1,064 cartons/acre. Similar yields resulted where polyethylene-coated papers were placed coated-side up or coated-side down. Paper mulches performed well with these un-staked tomatoes largely due to the abbreviated season (3.5 months) and reduced foot and machine traffic compared to tomatoes grown with the staked cultural system.

The effects of increased rates of N and K fertilizer on yield and fruit size of polyethylene mulched, stake-grown tomatoes, were evaluated over two spring and fall seasons in Immokalee (AREC) (Everett, 1976). Beds spaced 6-feet on center received 0, 54, 108, 162, 216, 270, 324, 432, 540, or 648 lb/acre N and 0, 75, 150, 225, 300, 375, 450, 600, 750, or 900 lb/acre K_2O from NH_4NO_3 and KNO_3 (70% NO_3-N and 30% NH_4-N). An 18-inch fertilizer band was applied from 10% of N for treatments through 324 lb/acre and 5% of N for treatments from 432 to 648 lb/acre. The remaining fertilizer was applied in surface bands 9 inches to each side of the plant row. Subsurface irrigation was applied in all experiments to Immokalee fine sand soils. Common N and K fertilizer rates used by area growers were cited as 350 lb/acre N and 475 lb/acre K_2O.

Marketable yield increases were only significant between 0 and 54 lb/acre N in fall 1974 (571 to 1130 cartons/acre, respectively). In spring 1975, yields were similar with or without N fertilizer, averaging 1058 cartons/acre. Heavy rains this season damaged roots and limited the crop to two harvests. Significant yield increases occurred in fall 1975 with N rates through 648 lb/acre N (2800 cartons/acre, 100% /RY) from 64% RY with 216 lb/acre N. In the spring 1976 experiment yields with 0 lb/acre N were nearly twice those of previous seasons with 0 lb/acre N. The author cited upward movement of nutrients with subsurface irrigation and the presence of a spodic soil horizon known to impede nutrient leaching. These same factors likely increased soluble salt content resulting in reduced yields with higher N rates in spring, 1976 (73% RY with 648 lb/acre N compared to 100% RY, 2734 cartons/acre, with 324 lb/acre N). Nitrogen fertilization did not affect fruit weight in any season, except with the initial N fertilization of 54 lb/acre N in the fall l975. The author concluded that tomatoes grown on previously cropped land reached optimum yield in the range of 162 to 270 lb/acre N.

Two spring tomato experiments were conducted on previously mulched beds, following a fall tomato crop, to test fertilizer rates and placement methods in a two crop system (Everett, 1978). Tomatoes grown in both the fall (first planting) and spring (second planting) were unstaked, single-harvest, “ground” tomatoes. Yields from the second planting were 50 to 60% lower than yields from the first planting, but estimated production costs were reduced 70 to 75% by reusing the mulched beds. Fertilizer was placed in a hole punched through the polyethylene at rates of 0, 0.5, 1.0, 2.0, or 4.0 oz per hole. Fertilizer holes were 8 inches to one side of the plant, 8 inches to both sides of the plant, or halfway between the plants (in the “drill”). Nitrogen treatments of 0, 65, 130, or 260 lb/acre (18-0-25 N-P_2O_5-K_2O fertilizer) were calculated based on 5808 plants/acre (5-foot row spacing). Fields were subsurface irrigated to maintain soil moisture at field capacity before planting the spring tomato crop (3 weeks after removing fall season plants).

Yields increased in both spring seasons with N treatments between 0 and 65 lb/acre to 90 and 94% RY each season. Yield increases with N treatments above 65 lb/acre were not significant. High, 100% RYs, occurred with 260 lb/acre N (714 cartons/acre) and with 130 lb/acre N (781 cartons/acre) in each respective spring season. Fruit size increased with 130 and 260 lb/acre N in the first season and increased only with 65 lb/acre N in the second season. Fertilizer placement did not affect yield or fruit size in either experiment season.

Nitrogen

Overhead Irrigation

Although fertilizer leaching losses were reduced with polyethylene mulching on overhead-irrigated fields, researchers found that soluble salt injury reduced yields with all of the fertilizer applied before mulching (Locascio et al., 1984). Researchers in a 1980 spring trial on Sparr sand sought to avoid this early plant fertilizer injury yet apply sufficient N for the late-season demand of fruit set and development. Four preplant N sources, KNO_3-Ca($NO_3)_2$, NH_4NO_3, sulfur-coated urea (SCU), or isobutyliene diurea (IBDU) were applied broadcast and incorporated preplant in single N-source treatments or paired with another for sixteen treatments, each applied at 200 lb/acre N. Prepared beds were spaced four feet apart.

Yield was highest with IBDU combined with KNO_3- Ca $(NO_3)_2$ in a 2 to 1 ratio (3,177 cartons/acre). Similar yields resulted with all combinations of IBDU or SCU and KNO_3-Ca($NO_3)_2$. Intermediate yields resulted with controlled-release nitrogen (CRN) sources (IBDU or SCU applied singly) and lowest yields resulted with soluble N sources (NH_4NO_3 or KNO_3-Ca$(NO_3)_2$) applied singly. Intermediate to low yields resulted with all combinations of NH_4NO_3 with other N sources, likely due to soluble salt effects of NH_4NO_3 on early plant growth. Researchers concluded that the N release rate of IBDU was superior to SCU, based on optimum tomato yields, and that yields with CRN sources were highest only when combined with soluble N sources.

The effect on tomato yields of mulch, N source, and irrigation method (overhead or drip) were evaluated for tomatoes grown on Plummer sand, spring 1981 (Sweeney et al., 1987). Nitrogen sources were a 50:50 mix of NH_4NO_3 and SCU or 100% NH_4NO_3. Mulched and overhead-irrigated tomatoes received 100% of the N and K preplant. Unmulched and overhead-irrigated tomatoes received 50% of the N and K preplant/incorporated and 50% side-dressed in two equal applications. Drip-irrigated tomatoes received 50% of N and K preplant and 50% through the drip line. Plant N recovery was measured by a ^{15}N-labeled NH_4NO_3, which was applied 100% preplant or in the split-N treatment as either the 50% preplant applied N or the 50% fertigated N. Rates of N, P_2O_5, and K_2O were 200-230-220 lb/acre, respectively, for beds spaced 4 feet on center.

Irrigation method did not affect marketable fruit yields of tomato. Polyethylene mulch, however, increased marketable fruit yields 25% (2,445 cartons/acre) over unmulched plants (1,842 cartons/acre). Likewise, mulch use enhanced N recovery by vegetative plant tissues which extracted 30% of the applied preplant N compared to 12 to 14% N recovery with the unmulched plants, averaged over irrigation methods. Nitrogen recovery in the fruit was not affected by mulch or irrigation method. Researchers found that less fertilizer N was needed when mineralized N from soil organic matter was present. Plant, fruits, and vegetative tissues recovered 30 to 60 lb/acre of soil N and an additional 110 to 150 lb/acre N from the 200 lb/acre of applied N. Marketable yields, in this study, were affected by N source. Twenty-one percent more fruits were harvested from plants fertilized with NH_4NO_3 (2,400 cartons/acre) than plants fertilized with 50:50, NH_4NO_3 : SCU (1,884 cartons/acre).

Unaccounted-for N amounted to 10 lb/acre N from mulched and overhead-irrigated beds. Researchers found that much more N was unaccounted for and presumed leached from drip-irrigated mulched or unmulched beds and from overhead-irrigated unmulched beds averaging 93 lb/acre of unaccounted-for N. Heavy leaching losses from drip-irrigated beds occurred despite seasonal water use of 7 inches compared to 16 inches of applied water with overhead irrigation. All tomatoes received 21 inches of rainfall, eight of which were moderate rainfall events (1 to 2 inches each).

Subsurface Irrigation

Starter fertilizer was applied at 20, 30, and 40 lb/acre N in Manatee County, fall 1988; in Palm Beach County, winter 1988-1989; and in Manatee County, spring 1989, respectively (Hochmuth et al., 1989). The starter fertilizer was supplemented with banded NH_4NO_3, KNO_3, and $Ca(NO_3)_2$. Nitrogen rates, calculated on the basis of a 6-foot bed center for the Manatee studies, were applied in bands and the beds were mulched with polyethylene. Water table height was continually measured by a water stage recorder.

Fall 1988 yields at Manatee County for a three-harvest season were lower than yields at the winter and spring sites. Yields were not significantly different with total (starter plus band-placed fertilizer) N rates from 160 to 280 lb/acre. A 98% RY (752 cartons/acre, based on a 13-foot row spacing) was achieved with 160 lb/acre N. Large fruit made up only 16% of the total marketable yield in this fall season of high rainfall. The yield with the grower fertilizer rate of 366 lb/acre N was 15% lower than with the reduced N rates (160 to 280 lb/acre N). At first flower sampling, leaf N concentrations were all high. Leaf N concentrations remained high through early harvest increasing linearly as N rate increased.

In a winter, 1988-1989, planting in Palm Beach County, fertilizer rates and yields were based on beds spaced on 5.5-foot centers. Increasing N rates from 160 to 280 lb/acre had no effect on yield. High yield occurred with 160 lb/acre N, 100% RY (1,153 cartons/acre). Leaf N concentrations at all sampling dates were high and not different with increasing N rates. Large fruit accounted for 20% of the total marketable yield.

Spring 1989 yields at Manatee County, with a two-harvest season, were based on 3,350 LBF (13-foot row spacing). A 99% RY (1308 cartons/acre) occurred with 180 lb/acre N and was not significantly improved with N rates of 240 and 300 lb/acre. Yields with the grower N rate of 402 lb/acre did not exceed yields with 180 lb/acre N. Leaf N concentrations were adequate and not different with increasing N rates. Large fruit comprised 61% of the total marketable yield. This season was marked by early drought that dropped the water table 36 inches below the bed surface on four occasions.

Fertilizer containing 30-110-60 lb/acre N, P_2O_5, K_2O was broadcast preplant on Oldsmar sand (0.62% organic matter) at Boynton Beach in the fall 1988 (Shuler et al., 1989). Additional fertilizers from KNO_3, $Ca(NO_3)_2$, and NH_4NO_3 were applied in double bands resulting in total N rates of 160, 220, or

280 lb/acre. These rates were tested against the grower program of 336 lb/acre N and 672 lb/acre K_2O. Beds were 5.25 feet apart, mulched with black polyethylene, and planted with Sunny tomatoes. Water levels were monitored using a water table recorder.

The greatest yield response occurred with 160 lb/acre N, 100% RY (1,922 cartons/acre). Yields dropped to 90 and 87% RY with 220 and 280 lb/acre N, respectively, and to 91% RY with the grower fertilization program. Leaf N concentrations were high and not different through all growth stages with all N rates.

Low organic matter, 0.6%, Myakka sand fields in Boca Raton were planted in fall 1990 with Sunny tomatoes (Shuler et al., 1991). Nitrogen rates of 160 and 220 lb/acre were compared to the grower rate of 328 lb/acre N (502 lb/acre K_2O). Beds were spaced 5 feet apart and fertilizer rates and yields were expresssed on 5- foot bed spacing. Preplant fertilizer, 48-160-40 lb/acre N, P_2O_5, K_2O, was broadcast and covered with black polyethylene mulch. The remaining N was applied in double bands 20 inches apart. Nitrogen sources were KNO_3, $Ca(NO_3)_2$, and NH_4NO_3 .

Yield response was greatest with 160 lb/acre N providing 100% RY (1597 cartons/acre). Relative yield dropped 5% with 220 lb/acre N. The grower yield was 92% of maximum. Leaf N concentrations through early fruit set ranged from 4.6 to 5.7%, higher than the adequate range of 2.5 to 4.0% (Hochmuth et al., 1991b). Nitrogen concentrations in leaves were not different through early fruit set with all N rates including the higher grower N rate. At harvest, leaf N concentrations fell to adequate levels with all N rates. Large fruit accounted for 20% of total marketable yield. Incidence of graywall increased from 150 to 195 cartons/acre with N rates between 160 and 220 lb/acre (significant at 5% probability).

Three N rates of 120, 180, and 240 lb/acre were tested at Boynton Beach, fall-winter 1991-1992 (Shuler et al., 1992). Beds were spaced 5 feet apart and fertilizer rates and yields were expressed on 5-foot bed spacing. Broadcast fertilizer containing 40-200-40 lb/acre N, P_2O_5, K_2O was applied in a 12-inch center band before bed shaping. White-on-black polyethylene mulch was pulled back for application of additional double-band fertilizer treatments of 80, 140, or 200 lb/acre N for total N rates of 120, 180, or 240 lb/acre.

Added N above 120 lb/acre had no significant effect on yield or fruit quality of 'Sunny' tomato. Plants with all N rates yielded 29 to 31% number-one grade large fruit. Equivalent yields were produced with 120 and 180 lb/acre N, 1638 and 1642 (100% RY) cartons/acre, respectively. Leaf N concentrations were well above the adequate concentration of 4.0% at first flower and at early fruit set with concentrations greater than 6.0% and 5.0% measured at each stage. Graywall affected 10% or less of the fruit and did not increase with N rate.

Tomatoes in four of the subsurface-irrigated trials reached maximum yields with 160 lb/acre N, while in two other trials, yields were maximized with 120 and 180 lb/acre N. In all trials, yields were maximized with N very near the current IFAS recommended 175 lb/acre N for tomato (Hochmuth and Hanlon, 1995). Increasing N above 175 lb/acre rarely increased yields or fruit quality. Leaf tissue sampling showed that tomato generally absorbed N at higher than adequate level. Increased N sometimes increased incidence of graywall in Sunny tomatoes.

Drip Irrigation

At the Gulf Coast Research and Education Center in Bradenton, yield responses to four N rates were tested over three growing seasons: fall 1983, spring 1984, and fall 1984 (Csizinszky et al., 1988). Nitrogen derived from NH_4-N (30%) and NO_3-N (70%) was applied, together with K, thirty percent incorporated preplant and 70% injected over the fourteen-week growing season. Polyethylene mulch was used, black in the spring and white in the fall seasons on beds spaced 4.5 feet on center. The fields were irrigated three times daily, 68% of total water requirements in early afternoon, and 16% each at early morning and late afternoon. Nutrient injection increased linearly through the fourteen-week season with heaviest fertilization in the last five weeks.

Marketable yields did not differ among N rates of 150, 300, 450, and 600 lb/acre in two fall seasons, 1983-1984. One hundred percent RY occurred with 300 and 450 lb/acre N (1,221 and 1,665 cartons/acre in 1983 and 1984, respectively). In the spring 1984 season, higher fertilizer rates reduced RY to 68% of the highest yield with 150 lb/acre N (1,050 cartons/acre) (Csizinszky et al., 1988). Leaf N concentrations measured at spring harvest 1984 increased with added N from an adequate level with 150 lb/acre N, 2.74%, to 3.62% with 600 lb/acre N. Adequate leaf N concentrations for the harvest period are between 2.0 and 3.0% (Hochmuth et al., 1991b).

Work with drip irrigation at the North Florida Research and Education Center, Quincy (Rhoads et al., 1988) was designed to test yield responses to N rates ranging from 0 to 200 lb/acre on the same field over spring 1983, 1984, and 1986 planting seasons. Beds were spaced 6 feet apart and soil moisture was monitored with tensiometers, that were placed 6 inches from the plant and 6 inches deep. A soybean crop grown in 1982 left sufficient residual N to return a total tomato yield of 99% RY (2,640 cartons/acre) with 60 lb/acre N fertilizer for the first crop season. Total yields responded similarly to N rates from 60 to 180 lb/acre in 1984. Slight responses occurred with 120 lb/acre N this season resulting in 98% RY (2,570 cartons/acre). Yields were similarly unaffected by changes in N source between NH_4NO_3 and $Ca(NO_3)_2$ or between preplant N application and split N applications; 40% preplant and 60% injected. In 1986, total tomato yields increased with N rates through 200 lb/acre (2,850 cartons/acre, 100% RY) and were also unaffected by preplant or injected fertilizer treatments.

Two N rates and two tensiometer settings, -10 and -15 centibars, were evaluated on sandy, flatwood soils over three seasons for effects on drip and subsurface-irrigated tomato production at the Gulf Coast Research and Education Center in Bradenton (Clark et al., 1989). Total N rates of 200 and 300 lb/acre were applied to subsurface irrigated fields. Nitrogen applied with drip irrigation was applied in graduated weekly amounts from a 4-0-8 (N-P_2O_5-K_2O) solution which resulted in differing cumulative N rates each year. The total drip-applied N rates in fall 1987 were 210 and 311 lb/acre N, 202 and 289 lb/acre N in spring 1988, and 176 and 266 lb/acre N in fall 1988. Fruits were harvested three times each season, except the fall 1988 season which was abbreviated to two harvests by a tropical storm. Beds were polyethylene mulched and spaced on 6-foot centers each season.

Tomato yields were not affected by fertilizer rate or by irrigation method (-10 centibar drip or subsurface irrigation) in fall 1,987 or spring 1988 trials resulting in average yields of 1,724 and 2,557 cartons/acre each year. Lower yields, 1,306 cartons/acre, occurred with the 300 lb/acre N, subsurface-irrigated treatment (fall 1988) compared to 1,585 cartons/acre with 266 lb of drip-applied N/acre irrigated to -10 centibars of soil moisture. Average yields with 202 and 289 lb/acre N and the drier -15 centibars drip-irrigated treatment were lower, 2,360 cartons/acre, compared to 2,570 cartons/acre average yields with the wetter -10 centibar drip irrigation treatment (spring 1988). With the drier irrigation treatment this season, large-size fruit yields were reduced to 78% of large fruit yields obtained with the -10 centibar and subsurface irrigated treatments averaged over both N rates. Soil moisture had no effect on marketable fruit or large-size fruit yields in either the fall of 1987 or 1988. Plants with all treatments had high concentrations of N in most recently matured whole leaves, taken at first flower and early fruit set, and leaf-tissue N concentrations remained adequate thereafter. All tomato plants initially received 400,000 gallons per acre of subsurface-applied water to raise the water table and establish the transplants. For the remainder of the trial, drip or subsurface irrigation was applied as specified. The total drip-applied water used was one-third of the total subsurface-applied water.

Using whole plant plus fruit analysis for N and K, drip-irrigated tomatoes were found more efficient in N utilization than the subsurface-irrigated tomato crop (spring 1988). At -15 centibars and 202 lb/acre N, 220 lb/acre N was removed from the soil. The subsurface-irrigated crop removed 163 lb/acre N with 200 lb/acre of applied N and removed 173 lb/acre N with 300 lb/acre of applied N (Clark et al., 1989). Drip irrigation proved to efficiently provide irrigation water and nutrients while maintaining high yields.

Limited research results on fertigated tomato grown on Rockdale soils prompted a Dade County fall/winter 1996 study (Carranza et al., 1996). Nitrogen and K were applied in a 4 x 4 factorial experiment. Nitrogen from NH_4NO_3 was applied, 20% preplant and 80% injected, as recommended in the Vegetable Production Guide for Florida (Hochmuth and Maynard, 1996). Bed spacing was not indicated in this study. High yields resulted with 150 lb/acre N, 99% RY (1,901 cartons/acre). Yield nearly doubled with 75 lb/acre N (94% RY) compared to yield with the check (zero N) treatment. No significant yield advantage occurred with 225 lb/acre N (100% RY).

Incidence of graywall and blotchy ripening (BR) in tomato, considered to be K deficiency disorders (Hochmuth et al., 1994a), were also studied at this site. Increasing K from 0 to 150 lb/acre K_2O had no effect on graywall or BER on this Dade county soil that tested medium high (AB-DPTA) in K. Nitrogen rate, however, had a positive effect on graywall incidence. Graywall incidence, averaged over both tested cultivars increased with N rates from 0 to 225 lb/acre (7 to 34 cartons). 'Agriset 761' had a 40% higher incidence of graywall than 'Sunny'.

Petiole sap nitrate concentrations were positively correlated with optimum tomato yields in south Florida subsurface-irrigated trials and optimum sap nitrate and K ranges were published (Hochmuth, 1994). Researchers at the North Florida Research and Education Center, Quincy, designed spring and fall 1995 experiments to test these petiole-sap nitrate levels against optimum tomato yields on a drip-irrigated north Florida site (Rhoads et al., 1996). In the spring, N was applied either 100% preplant-incorporated or 40% preplant-incorporated with 10% injected six times between 3 and 13 weeks from transplanting. All N was applied preplant in the fall. Five N rates: 0, 60, 120, 180, and 240 lb/acre were applied from NH_4NO_3 in both seasons. The beds were spaced 6 feet apart and mulched with black polyethylene in the spring and white in the fall.

Battery-operated ion-specific meters provided instant sap nitrate analysis and results were comparable to the South Florida standards derived with colorimetric procedures (Rhoads et al., 1996). Tomato yields were highly correlated with petiole sap nitrate concentrations for the period of 4 to 10 weeks after planting. Ten weeks after transplanting, applied N fertilizer ceased to affect yield response in either spring or fall planting seasons. Researchers concluded that field ion meters were effective for mid-season monitoring of tomato N needs. Yields with preplant-applied fertilizers were not different above 120 lb/acre N in spring and above 60 lb/acre N in fall trials. Reduced fall yields (1280 carton/acre) in the presence of N pointed to other factors such as poor fruit set due to high day/night temperatures that limited tomato yield. Authors noted that tomato yields would likely respond to N rates nearer the recommended rate of 175 lb/acre during a cooler season. The highest yielding plants were grown with 180 lb/acre N applied 40% preplant and the remainder injected (2,268 cartons/acre). These yields were 7% higher than yields of plants with 100% preplant-applied fertilizer with the same N rate.

A lack of experiments with fall-grown tomato in north Florida prompted 1995 and 1997 experiments in Gadsen County (Rhoads, 1997). Particular attention was given to petiole sap NO_3-N concentrations measured with Cardy ion meters. Nitrogen was applied 100% preplant from NH_4NO_3 at N rates of 0, 60, 120, 180, and 240 lb/acre. Bed spacing was not indicated in this study. High temperatures in fall 1995 were suspected of limiting yield response (due to poor fruit set) to N applied that season. Significant yield increases occurred in both seasons between 0 and 60 lb/acre N with 95 and 96% RY (1260 and 1,996 cartons/acre, respectively) occurring with the 60 lb/acre N rate. Yield increases to 100% RY with 180 lb/acre N (1332 cartons/acre) and 120 lb/acre N (2082 cartons/acre), in each respective season, were insignificant. Comparison of petiole sap NO_3 - N concentrations averaged over both seasons confirmed a range of N sufficiency concentrations in plants grown with 60 lb/acre N (low) to 120 lb/acre N (high). An adequate N rate for fall grown tomato was given as 120 lb/acre. Researchers suggested that N fertilization efficiency may be improved by application of 40 lb/acre N at preplant and 15 lb/acre N injected weekly from weeks 5 through 8. The weekly injected N rate may be adjusted to meet petiole sap N sufficiency concentrations monitored through week ten.

Findings in spring 1993 (Quincy) and spring 1994 (Gainesville) also indicated that petiole sap N concentrations at mid-season correlated with yield (Locascio et al., 1997b). Beds, spaced 6 feet apart, were mulched with polyethylene and irrigated when soil water tension reached -10 centibars. The total applied N was 175 lb/acre at both sites. Yields were 16% higher when 60% of the N and K fertilizers were injected than when all were applied preplant (1328 cartons/acre) at Gainesville. Tomato yields in the Quincy trials were either unaffected by application method or had 16% higher yields with all preplant applied fertilizer than with split-applied N (1,738 cartons/acre).

Yield responses to the time of N and K application, either preplant only or preplant with fertigation, were dependent upon soil type. Less yield response resulted with fertigated N on heavier soils, such as Orangeburg loamy sands in Quincy, compared to the lighter Arredondo fine sands in Gainesville. Earlier research supported this finding (Locascio et al., 1989). Yields averaged over 1984 and 1985 on Arredondo fine sands resulted in increased late-season extra-large and large fruit yields (489 and 360 cartons/acre, respectively) with 60% drip applied N and K compared to yield response with all preplant applied N and K (300 and 293 cartons/acre, respectively). Researchers noted that drip-applied nutrients extended the season of large fruit harvest by maintaining plant nutrient concentrations late in the season. Results of this experiment were repeated in 1988 at Gainesville (Locascio and Smajstrla, 1989). When 60% of the applied N and K were fertigated, yields of extra-large fruits were 40% higher than extra-large fruit yields where N and K were applied 100% preplant. Yields of large and total marketable fruits were also 10% higher with the same fertigated treatment compared to 100% preplant applied fertilizer. When percentages of fertigated N and K were increased above 50% to 75 and 100%, yields declined linearly (2,473, 2,459, and 2,060 cartons/acre, respectively) in other Arredondo fine sand fertigation research (Dangler and Locascio, 1990). Average yields from 1984 and 1985 seasons resulted in higher yields of medium-size early fruit, mid-season large fruit, and total season large fruit with 50% fertigated N and K (or N).

Experimentation with fertigation continued in Gainesville on Millhopper fine sand soil in the spring of 1996 (Locascio et al., 1996). Two-foot wide beds were prepared on six-foot centers and 40% of the total N was broadcast on the bed surface, tilled, and mulched with polyethylene. Agriset 761 tomato transplants were set March 14 and fertigation began April 3. Equal amounts of N were applied each week through ten weeks of fertigation. Total N (NH_4NO_3) rates were 120, 180, 240, or 300 lb/acre. Drip irrigation was applied to maintain soil moisture at -10 centibars by tensiometer with one overhead irrigation for freeze protection. Marketable yields responded quadratically to increasing N rates leveling off above 180 lb/acre N with 240, and 300 lb/acre N. Respective RYs for these N rates were 88, 98, and 100% RY (2,270 cartons/acre). Leaf tissue N concentrations were adequate (2.5 - 4.0%) above 180 lb/acre N (> 2.7%).

Numerous drip-irrigation trials, summarized above, were treated with soluble N sources applied at preplant or at preplant and fertigated throughout the crop season. Tomato yields generally maximized at or near the current recommended 175 lb/acre N rate. Researchers, field-testing a polymer-coated fertilizer (Meister fertilizer; Helena Chem. Co., Memphis, TN), hoped to improve the efficiency of N fertilizer on tomato (Hochmuth, 1997). Trials were conducted on Arredondo fine sands near Gainesville, spring 1997, on raised two-foot wide beds placed on four-foot centers (N rate calculations and expressions were based on six-foot bed centers). The polymer-coated, 19 N-5P_2O_5-14K_2O, fertilizer was compared to soluble N and K sources (NH_4NO_3 and KCl). Fertilizers applied to the bed surface were broadcast and tilled or applied in a four-inch off-center band and pressed into the soil. All beds were mulched with black polyethylene, planted with 'Agriset 761' tomato, and drip-irrigated to -10 centibars soil moisture.

Interactions occurred in the first, third, and overall season harvests affecting marketable fruit yields, all fruit grades initially, and then extra-large and large fruit yields only. Yields of early fruit from all fruit grades increased when soluble fertilizers were applied broadcast and when polymer-coated fertilizer was placed in bands (yields averaged over all applied N rates). Total marketable yields and yields of large fruit also increased with the same fertilizer placement methods. Nitrogen rate increases with the polymer-coated material resulted in higher early yields, more extra-large, large, and total marketable fruits with increasing N rates from 75 to 175 lb/acre N at the third harvest. With the soluble N source, yields decreased slightly with higher N rates. Overall, plants fertilized with the polymer-coated fertilizer produced 40 to 50% more fruits than plants fertilized with soluble N (3,326 over 1,859 cartons/acre, respectively) and resulted in significantly higher yields, 80%, 86%, and 100% RY (3,326 cartons/acre) with N rates of 75, 125, and 175 lb/acre N. Yields well above the state average yields of 1,216 cartons/acre (1996) were likely due to increased plant density with plant rows spaced four feet instead of the standard six feet on center. Cull fruit yields were similar with both fertilizers and were not changed by fertilizer placement or rate.

Overfertilization with N has been measured in terms of reduced yield but, recent findings tie high rates of N application (>175 lb/acre) with increased populations of western flower thrips (Funderburk et al., 1997). As a vector of the disease, tomato spotted wilt virus, increased western flower thrips populations resulted in higher disease incidence in Quincy grown tomatoes (1996 and 1997). Plants were fertilized with 190 or 275 lb/acre N, mulched with black or silver plastic, and drip-irrigated. Beds were spaced 6-feet apart. Pesticides were not applied to thrips or their natural predators. Tests on the effect of N rates (0, 60, 120, 180, and 240 lb/acre) on flower N concentration, amino acid quality, flower number, and plant size were also conducted in 1997.

In 1996, adult thrips populations were generally lowest on silver-mulched beds fertilized with the recommended N rate. Occurrence of tomato spotted wilt virus, measured in 1997, was lowest, 23.6%, on silver-mulched beds fertilized with the recommended N rate (30% disease occurrence with the higher N rate). Disease occurrence was highest, 46.9%, where black plastic was applied to beds fertilized with the higher N rate (40% disease occurrence with the recommended N rate). As a simple disease control measure, researchers recommended use of silver mulch with the recommended N rate. Analysis of flower tissue was not completed for the study, but, analysis of plant sepal tissue revealed higher protein concentrations in the sepals of plants fertilized with excess N. Although thrips are commonly seen clustered on tomato plant sepals, researchers advised additional study to confirm an association. In general, increased N fertilization significantly increased plant size and flower number in both seasons without a subsequent yield increase.

In fourteen of the fifteen tomato fertilization trials summarized above, optimum yields resulted with N rates between 60 and 200 lb/acre N. Residual N from a previous soybean crop was responsible for high yield response with only 60 lb/acre N. Yields only occasionally increased with N rates above 200 lb/acre and, in one trial, RY fell to 68% with 600 lb/acre N compared to 100% RY with 150 lb/acre N. Slightly more large fruits were reported at one location with 300 lb/acre N. Split N applications (20 to 40% preplant and the remainder injected) increased tomato yields 7 and 16% in two trials, reduced yields 14% in a third trial, and did not differ from yields with all preplant applied N in four other trials. Split N application proved most effective on some sandy soils in Gainesville and least effective on Orangeburg loamy sands in Quincy. High N fertilization (to 240 lb/acre) was found to increase incidence of the disease tomato spotted wilt virus. Researchers found that populations of the western flower thrips, the vector for this virus, were increased where plants were fertilized with high N rates.

Field use of the Cardy ion meter to monitor petiole-sap nitrate concentrations proved a reliable and quick mid-season (4 to 10 weeks from transplant) method of assessing plant N status. Controlled-release polymer-coated fertilizer at 175 lb/acre N proved superior to broadcast or banded soluble N sources resulting in high yields with one preplant band application. The practice of drip irrigation reduced water usage to one-third of the total water used with comparable subsurface-irrigated tomatoes.

Nitrogen Summary

Tomato yields in 75% of all experiments did not increase with N rates above the recommended rate of 175 lb/acre (indicated by the dashed line in Fig. 1).

Nitrogen rates below 175 lb/acre were not evaluated in three experiments that optimized above 175 lb/acre N (Clark et al., 1989). Among these experiments, yields were not significantly different with N rates from 200 to 300 lb/acre. Yield data from one experiment indicated a clear negative response with N above the recommended rate (Csizinszky et al., 1988). Yield responses to N were similar for tomatoes grown with subsurface or drip irrigation. Water savings with drip-irrigated tomato, however, provided optimum yields with one-third of the water applied by subsurface irrigation and up to one-half of the water applied by overhead irrigation. Researchers found that despite the significantly lower water rates used with mulched and drip-irrigated tomato, N leaching losses in one study accounted for 47% of the applied N compared to 5% of the applied N with mulched and overhead irrigated beds. On mulched, overhead-irrigated tomato trials, yields were highest with IBDU in combination with KNO_3 - $Ca(NO_3)_2$ where all fertilizers were applied preplant. Soluble salt injury resulted in these trials where preplant NH_4NO_3 was applied alone or in combination with CRN sources.

Response of tomato to fertigated N was related to soil type. Tomato yields were 16% higher with 175 lb/acre N (40% preplant applied, 60% fertigated) on Arredondo sands in Gainesville compared to yields on loamy soils of the Florida panhandle. When yields responded to higher than the recommended N rate on sandy soils nutrient leaching was suspected. Incidence of graywall in 'Sunny' tomato was not consistently affected by N application, however, when affected, high rates of N increased graywall incidence. Incidence of the disease, tomato spotted wilt virus, was also found to increase with excess N application to 275 lb/acre. Incidence of the disease was tied to higher populations of the disease vector, the western flower thrips, where plants were fertilized with the higher N rate.

Phosphorus and Potassium Soil Testing

Knowledge of soil nutrient levels, particularly P and K, before planting is the starting point to predicting tomato response to varying rates of applied nutrient. Using soil testing to determine preplant soil nutrient concentrations provides information so research results may be reviewed for degree of support of existing fertilization recommendations. The Mehlich-1 (double-acid) solution is the current extractant used by Florida and several other southeastern US states for sandy soils.

Mehlich-1 extractant indices (expressed as ppm soil-extracted nutrient) are classified as very low, low, medium, high, and very high, and a crop specific fertilizer recommendation is made from that classification (Hochmuth et al., 1995). The M-1 solution became the accepted extractant standard in 1979 at the University of Florida. Previous to M-1, ammonium acetate and water extractants were used. Indices recorded from these methods cannot be directly equated with M-1 indices or fertilizer recommendation rates but the review of research results from studies with these extractants presents a profile of tomato response to fertilizer under varying conditions. Water management practices, fertilizer sources and application methods, and the effect of mulch in the nutrient management system, should also be considered in P and K fertilization programs.

Phosphorus

Soil pH on an Immokalee fine sand was 4.7, and hydrated lime was applied in October 1961 at rates of 500, 2,000, and 5,000 lb/acre (Hortenstine and Stall, 1962). Subplots 40 x 14 foot, with 78 subplots per acre, were treated with 100, 300, and 910 lb/acre P_2O_5 in November and N, K_2O, and Mg were applied through the growing season at respective rates of 220, 250, and 80 lb/acre. Irrigation method, mulch use, or research location, were not specified.

Calcium present in hydrated lime increased individual tomato fruit weight while P increased vegetation, flowering, and fruit set. Soils with high lime treatments and low P (100 lb/acre P_2O_5) resulted in plants with P deficiency symptoms. The reverse application of low lime, (500 lb/acre) and high P_2O_5, (910 lb/acre) resulted in nutrient toxicity symptoms expressed as leaf roll. Higher P rates also simultaneously resulted in lower soil pH, reduced nitrification by microorganisms, and immobilization of Ca in the soil. Adequate rates of lime and P for this soil were 5,000 lb/acre lime and 300 lb/acre P_2O_5. These combined rates brought soil pH to near 6.5, recommended for tomato, with soil samples taken in December and April having pH values of 6.2 and 6.3, respectively. Marketable yield with 300 lb/acre P_2O_5 was 88% RY, (360 cartons/acre, based on 115 lb/subplot and 78 subplots/acre, bed spacing not indicated). An additional 600 lb/acre of P_2O_5 increased the RY to 100%, but was not cost effective.

Tomato response to added P on acidic, poorly-drained Immokalee sand was studied over three winter seasons near Immokalee (Rhue and Everett, 1987). Lime and P were needed to raise the pH from 5.0 to 6.5 and supplement the very low (9 ppm) M-1 soil-extracted P. Typical beds were arranged six feet apart, mulched with black polyethylene, and subsurface irrigated with the water table kept 16 inches below the bed surface. Dolomitic lime was applied annually in November at 0, 2,000, and 4,000 lb/acre (0, 1, and 2 times the amount required to reach 6.5 pH). Concentrated superphosphate (CSP) was broadcast and incorporated in January 1982 at 0, 250, 500, and 750 lb/acre P_2O_5 (150 lb/acre was recommended for this site) with starter applications of N and K_2O of 25 and 40 lb/acre. Double bands of 180 lb/acre N and 250 lb/acre K_2O were applied last to the bed shoulders. The same N and K fertilizer treatments were used in 1983 and 1984 except P application was reduced to 0 or 40 lb/acre P_2O_5 (CSP) broadcast.

Tomato yields on unlimed soils were not different with 0 or 250 lb/acre applied P_2O_5 but, declined 35% with 500 lb/acre P_2O_5 (1600 cartons/acre). Two probabilities were cited for reduced yields, the first was nutrient toxicity with excess P and the second related to decreasing leaf Mg concentrations with increases in P rate on unlimed soils. Limed soil had significantly more extractable P, but soils did not retain increased P concentrations into the next growing season. The first season, when 0, 250, 500, and 750 lb/acre P_2O_5 had been incorporated preplant, the M-1 soil-extracted P measured at harvest was high. Phosphorus concentrations were low in samples taken before fertilization in 1983 and became very low in 1984. Leaching of P was likely on these very sandy, unlimed soils, as well as on sandy limed soils with successive annual P applications. Phosphorus under these conditions should be managed as a mobile nutrient and researchers recommended seasonal P applications not to exceed crop uptake to prevent leaching losses. High yield occurred in the first trial year (1982) with 2,000 lb/acre lime and with 250 lb/acre P_2O_5, 100% RY (3,070 cartons/acre). An additional 40 lb/acre P_2O_5 applied in 1983 and 1984 increased yields 10% (1830 and 2,000 cartons/acre respectively) above yields with 0 lb/acre P_2O_5.

Repeated annual applications of P on neutral pH EauGallie fine sand at the Gulf Coast Research Center in Bradenton increased soil P concentrations (Clark et al., 1989). Soil pH remained at or near 7.0 in this three-season study and represented typical production soils in west-central and southwest Florida. Concentrated superphosphate with micronutrients was broadcast uniformly at 375 lb/acre P_2O_5 each season: fall 1987, spring and fall 1988. Successive tomato crops failed to deplete soil P concentrations, rather soil P concentrations (M-1 extracted at preplant) increased from low to high concentrations over the three seasons. Yield responses to increased soil P concentrations were not evaluated. Previously cropped soil with near neutral pH often retains sufficient P so that P fertilization is not needed. IFAS recommends withholding P fertilizer when soils test high for P. On soils that test low for P, application of 120 lb/acre P_2O_5 is recommended and 100 lb/acre P_2O_5 is recommended for medium P soils.

Authors of research conducted in Boynton Beach, 1994-1995 fall/winter, concluded that excess applied P did not enhance tomato yields (Shuler and Hochmuth, 1995). Mehlich-1 soil indices of 222 ppm P for the soil at this site exceeded the 60 ppm needed for a very high soil P interpretation. Response to P was not predicted for this site but: 0, 50, 100, 150 lb/acre P_2O_5, and the grower rate of 200 lb/acre P_2O_5 were applied to test yield response to P fertilization of a high-P soil. Phosphorus treatments combined with micronutrients, 39 lb/acre N, and 50 lb/acre K_2O were broadcast in a 12 to 18 inch band and incorporated at bed formation. Grower N and K_2O rates were applied in double bands at 306 and 600 lb/acre, respectively. Single beds, 5 feet on center and 24 feet in length were mulched with black polyethylene, planted with 'Solimar' transplants, and subsurface irrigated.

Total marketable yield was not affected by added P through 200 lb/acre P_2O_5. The yield average over all P rates was 2600 cartons/acre. High temperatures and tropical storm 'Gordon' claimed 10% of the plants in the first four weeks followed by conducive growing conditions for the remainder of the season. Phosphorus concentrations from whole leaf tissue samples were high at early fruit set and adequate through harvest with all P rates. Soil P concentrations had increased through 444 ppm with P fertilization to 200 lb/acre P_2O_5 at the early soil sampling. Soil P concentration remained unchanged from the prefertilization value through the season with the zero P treatment. Soil Zn concentrations decreased 40% with added P.

Further testing of tomato yield response in the presence of high soil P occurred on Millhopper fine sands near Gainesville (Locascio et al., 1996). Soil at this spring 1996 trial site tested very high (92 ppm) in M-1 soil-extracted P and additional P was not recommended. Beds two-foot wide and six feet on center received broadcast applications of N, P (CSP), and K which were incorporated, mulched in black polyethylene, and drip-irrigated to maintain soil moisture at -10 centibars by tensiometer. Phosphorus was applied at 0 or 160 lb/acre P_2O_5. Soil P concentrations were higher (1% level) through June 17 where P had been applied. Although marketable fruit yields were not affected by higher soil P concentrations, plant growth at the May 17 whole-plant sampling date had accelerated where P was applied. Larger plants at this sampling contained 13% more P (significant at 1%) in whole plant analysis than plants grown with zero added P.

Phosphorus Summary

Successive seasonal applications of P, at rates above M-1 recommendations, accumulate in most soils but provide no yield advantage. In the presence of high soil P, mid-season plant growth was accelerated over plants grown on high P soils without added P. Plants grown with high P fertilization also contained 13% more P by whole plant analysis but did not yield more fruit. On acidic soils, P did not accumulate and P leaching occurred. Application of P should not exceed crop uptake on coarse sandy soils to prevent possible interim leaching losses between crop seasons. Phosphorus application on acidic, unlimed soils caused nutrient toxicity symptoms in tomato as well as restricting Ca, Mg, and N uptake from the soil solution. On limed, very low M-1 P soils, up to 250 lb/acre P_2O_5 were needed for maximum yield. More research is needed to better relate required P fertilization with the M-1 soil test index.

Potassium

Subsurface Irrigation

A fall/winter 1988-1989 trial conducted in Boynton Beach evaluated response of tomato to four K_2O rates of 80, 160, 240, and 440 lb/acre and the grower rate of 672 lb/acre K_2O (Shuler et al., 1989). Fertilizers were derived from KNO_3, $Ca(NO_3)_2$, and NH_4NO_3. Soil tested very low (16 ppm) in extracted K using M-1 extractant and 160 lb/acre K_2O was the recommended rate in 1989 for very low-K soils (Hochmuth and Hanlon, 1989; Kidder et al., 1989). A starter fertilizer with 60 lb/acre K_2O was broadcast and the remaining K was double banded to equal the total rates listed above. Single beds were 5.25 x 23.8 feet and contained 12 to 13 plants. Subsurface water levels were monitored with a water table recorder.

Total marketable yield increased linearly with increases in K_2O through 240 lb/acre, 100% RY (2160 cartons/acre). Yield declined 24% with grower N and K_2O rates of 336 and 672 lb/acre. Leaf K concentrations at first flower and early fruit set were adequate with 240 lb/acre K_2O, but deficient at first flower with 160 lb/acre K_2O. Leaves with all experimental K rates were considered K deficient at first harvest with leaf K concentrations less than 2.0% (Hochmuth et al., 1991b). Soil had returned to very low M-1 potassium levels after harvest and researchers noted that removal of mulch and plant material allowed residual soil K to leach. Band fertilization with 672 lb/acre K_2O resulted in residual K (76 ppm) in the band at the end of the season. The yield response of subsurface-irrigated tomato to higher K rates in this study and others (Locascio et al., 1997) led to a K rate revision for very low-K soils from the 1989 standard recommendation of 160 lb/acre K_2O (Kidder et al., 1989) to 225 lb/acre K_2O (Hochmuth and Hanlon, 1995).

Starter K_2O was applied to commercial fields at rates of 40, 60, and 80 lb/acre in Manatee (fall), Palm Beach (winter), and Manatee (spring), respectively (Hochmuth et al., 1991a). Subsurface irrigation was managed by the grower on polyethylene-mulched fields. Experimental rates of K_2O were applied in shoulder bands at varying rates depending on the specific experiment. Fertilizer sources were as follows: KNO_3, $Ca(NO_3)_2$, NH_4NO_3, and K_2SO_4. Sunny transplants were used for all trials.

Tomato yields were the same with all experimental K rates during the warm fall (1988) and spring (1989) seasons at Manatee County. High RYs were 98, 100, and 97% with 80, 160, and 240 lb/acre K_2O (1988) and 96, 100, and 99% with 120, 200, and 280 lb/acre K_2O (1989). High yields were 748 and 1326 cartons/acre (13-foot row spacing, K rates calculated on 6-foot bed centers) with 160 and 200 lb/acre K_2O applied each year. Acceptable yields occurred with the 1989 recommendations for very low and low-K soils, 160 lb/acre K_2O (fall 1988), and 130 lb/acre K_2O (spring 1989), respectively. Satisfactory leaf K concentrations, above the adequate range, occurred with all K rates during these seasons. In the cooler winter season in Palm Beach County, 1988-1989, tomato yields responded linearly to added K through the 240 lb/acre K_2O rate, 100% RY (2,160 cartons/acre). Leaf K concentrations were deficient for lesser K rates, 80 and 160 lb/acre K_2O, during this winter sampling. The 1989 recommendation of 160 lb/acre K_2O for very low-K soils (16 ppm), was insufficient. Winter yields requiring 240 lb/acre K_2O responded near the revised recommendation (Hochmuth and Hanlon, 1995) of 225 lb/acre K_2O. Higher grower K rates used over all three seasons, 530, 625, and 393 lb/acre K_2O resulted in yields 15% lower, equal to, and slightly greater than yields with 240 lb/acre K_2O for fall, winter, and spring trials, respectively.

A fall/winter 1991 experiment in Boynton Beach evaluated marketable yield response to three reduced N rates, four reduced K rates, and the grower rates of 652 lb/acre K_2O, and 346 lb/acre N (Hochmuth et al., 1992; Shuler et al., 1992). Mehlich-1 soil-extracted K was low, 20 ppm, and 130 lb/acre K_2O were recommended based on 1989 standards (Kidder et al., 1989). All treatments consisted of 40-200-40 lb/acre N-P_2O_5-K_2O preplant broadcast fertilizer. The remaining K_2O was double banded for total K_2O rates of 80, 160, 240, and 320 lb/acre. Beds were spaced 5 feet on center with fertilizer calculations based on this spacing. Beds were mulched with white-on-black polyethylene and Sunny tomatoes were harvested three times.

The 100% RY value (1,770 cartons/acre) occurred with 240 lb/acre K_2O with a 94% RY with 160 lb/acre K_2O, in a quadratic response to applied K. This yield response exceeded the 130 lb/acre K_2O 1989 recommendation and supported the higher 1995 recommendation of 150 lb/acre K_2O for low-K soils. Yields did not increase with 320 lb/acre K_2O, nor were they improved with the commercial rate of 652 lb/acre K_2O (1907 cartons/acre). Extra-large fruit yields increased 45% with 160 lb/acre K_2O over the 80 lb/acre K_2O rate and leveled off thereafter. Adequate leaf K concentrations did not increase significantly with K rate at first flower, but increased linearly at early fruit set. Soil samples taken through the fertilizer band after harvest resulted in high concentrations of M-1 soil-extracted K, 490 ppm from the 612 lb/acre banded K_2O and 221, 93, 37, and 19 ppm from the reduced K rates 280, 200, 120, and 40 lb/acre banded K_2O, respectively. Increasing K rates from 80 to 320 lb/acre K_2O did not significantly affect incidence of graywall and blotchy ripening (BR).

A winter 1991-1992 trial in Boca Raton, tested reduced rates of soluble and controlled-release (CR) K sources against a commercial fertilizer treatment (Shuler, 1992). Mehlich-1 soil testing revealed very low levels of soil K (4 ppm) and 160 lb/acre K_2O was recommended in 1989. All treatments consisted of 40-20-60 lb/acre N, P_2O_5, K_2O broadcast preplant with remaining treatments double banded for total K_2O rates of 180 and 260 lb/acre (160 lb/acre N). The grower applied 300 lb/acre K_2O, using broadcast and band placement, with 200 lb/acre N. Single-bed plots were 5.5 x 21.8 feet with eight Mountain Pride tomato plants per bed. Beds were covered with silver-topped polyethylene mulch.

Following five harvests, marketable yield response was no different with any K rate or K source. Yield response with soluble K sources was slightly higher with 180 lb/acre K_2O, 100% RY (1,745 cartons/acre) and lower with 260 lb/acre K_2O, 89% RY. When half of the band-applied K_2O was from a CR source, equally high yields (1,828 cartons/acre) were produced with 180 lb/acre K_2O. Large fruit accounted for 48% of this yield while other treatments resulted in 43% large fruit (Shuler, 1992). Tomato yield response to the grower rate resulted in 1,870 cartons/acre. Leaf-tissue K concentration was adequate with all treatments sampled at mature green fruit stage. Tissue K concentration was the same for plants receiving all soluble-K fertilizer and plants receiving half soluble and half CR forms of K. Soil samples taken through the fertilizer band after harvest had 409 ppm K with the commercial application of 300 lb/acre K_2O (200 lb/acre banded). Lesser banded amounts, 120 and 160 lb/acre soluble K_2O returned 55 and 89 ppm M-1 K in the fertilizer band.

Graywall and BR incidence decreased with higher K_2O rates, 52 to 20 cartons/acre as K_2O increased from 180 to 260 lb/acre K_2O, consistent with the theory that these disorders are related to K deficiency. When K was reduced to 180 lb/acre K_2O but, half in CR form, fewer cartons of graywall and BR fruit were harvested, 17 cartons/acre (Shuler, 1992). Reduced graywall and BR with CR fertilizer was probably due to more consistent availability of K. Similar leaf N and K concentrations indicated factors in addition to K were involved in these disorders.

Three Bradenton trials, two spring and one fall, and one West Palm Beach winter trial evaluated the effects of K source and rate on subsurface-irrigated, polyethylene-mulched tomato (Locascio et al., 1994; Locascio et al., 1997a). The bed spacing for each experiment was not cited.

Neither the 1989 recommendation of 130 lb/acre K_2O, nor the 1995 recommendation of 150 lb/acre K_2O optimized yields for M-1 low-K (25 and 26 ppm) soils in Bradenton spring trials, 1991 and 1992. Yields increased linearly in spring 1991 and increased quadratically in 1992 leveling off above 240 lb/acre K_2O, 93% RY (2,535 cartons/acre). One hundred percent RY occurred at both trials with 325 lb/acre K_2O. Researchers cited the inefficiency of banded-K fertilizers when post-harvest M-1 soil tests revealed large amounts of residual K_2O in the band (all of the N and K_2O were applied in two bands on the bed shoulder). Despite the higher yield demand for K, tomato leaf K concentrations measured in leaves taken at mid-season (spring 1992) were adequate with even the lowest K rate of 80 lb/acre K_2O. In research with pepper (Hochmuth et al., 1994b), band placement was also found the least effective placement method with subsurface-irrigation.

Plants growing in a M-1 very low K (15 ppm) soil in Bradenton, fall 1992, produced 100% RY (3200 cartons/acre) with 240 lb/acre K_2O. The maximum yield exceeded the 160 lb/acre K_2O rate recommended in 1989 and was nearer the 225 lb/acre K_2O rate recommended in 1995. Yields increased quadratically through 0, 80, and 160 lb/acre K_2O, maximizing with 240 lb/acre K_2O, and declining to 93% RY with 325 lb/acre K_2O. Band placement of K_2O was used in this trial. Mid-season leaf concentrations were adequate with all K rates, increasing linearly with K_2O treatments from 80 to 320 lb/acre. Yields varied less than 3% with K sources, KCl, K_2SO_4, or KNO_3 at two of the three Bradenton trials but, in the spring of 1992 marketable fruit yield increased 19% with KNO_3.

In West Palm Beach, winter 1990-1991, 80 lb/acre K_2O was broadcast preplant and the remainder was banded on the bed shoulders for total K_2O rates of 80, 160, 240, 320 and 400 lb/acre (Locascio et al., 1997a; Shuler et al., 1991). The bed spacing was not indicated in this experiment. Yields responded quadratically to increasing K rates leveling off with 320 lb K_2O/acre, 100% RY (1,850 cartons/acre). Yields optimized above the 1989 recommended rate of 160 lb/acre K_2O for this very low (12 ppm) K soil and above the 1995 recommended rate of 225 lb/acre K_2O. Leaf K concentrations at mid-season were adequate above 240 lb/acre K_2O, but deficient with 80 and 160 lb/acre. A dry period between October 15 through December 20 (2.0 inches of rain) was cited for the inefficient utilization of banded-K fertilizer which resulted in the higher-than-expected fertilizer demand. Significant amounts of K remained in the fertilizer band after harvest , ranging from 34 to 674 ppm with treatments of 80 to 502 lb/acre K_2O (post harvest M-1 soil samples).

In eight of twelve subsurface irrigated experiments, yield was maximized at or below 240 lb/acre K_2O. In some studies, responses to more K was observed. Shoulder band applications of N and K_2O were used in all experiments and yields responded similarly to 0 through 80 lb/acre K_2O broadcast preplant. Poor absorption of band-applied K by tomato was apparent in some instances when leaf K concentrations were deficient despite high amounts of residual K extracted through the fertilizer band post harvest. Low absorption of band-applied K was exaggerated by dry weather and fluctuations in soil water conditions. Higher grower K_2O rates up to 672 lb/acre caused yields to drop 15 to 25% or show no increase over lower fertilization rates. Equivalent yields resulted with all K sources including KCl, K_2SO_4, KNO_3, soluble sources, or half soluble: half CR sources. Graywall incidence decreased 9% (not significant) with K_2O increases up to 320 lb/acre.

Drip Irrigation

In studies in Quincy, Gainesville, and Live Oak, the effects of K rate and source on drip-irrigated Sunny tomato were evaluated in spring seasons 1986, 1990, and 1991 (Locascio et al., 1994; Locascio et al., 1997a). Micronutrient mix was broadcast preplant at 40 lb/acre in 1986 with all of the K fertilizer (either 215 or 430 lb/acre K_2O). Soil beds at all sites were mulched with black polyethylene (bed spacing was not indicated).

Medium M-1 K concentrations of 60 and 50 ppm, were reported in the spring 1986 at Gainesville and Quincy, respectively and 100 lb/acre K_2O was recommended. Yield responses to 215 and 430 lb/acre K_2O were similar at both sites. Relative yields with 215 lb/acre K_2O were 99% (2,970 cartons/acre) at Quincy and 95% (2,070 cartons/acre) at Gainesville. Yields were also similar with both KCl and K_2SO_4 potassium sources. Leaf K concentration was adequate in the Gainesville study, data were not presented for Quincy.

Two additional Quincy studies were conducted in spring 1990 and 1991 where the soil M-1 potassium indices were medium (37 ppm), and low (34 ppm). All of the K fertilizer was broadcast preplant. Yield in 1990 was maximized within the medium recommendation of 100 lb/acre K_2O with non-significant yield increases above 80 lb/acre K_2O (97% RY) (2,590 cartons/acre). Likewise in 1991, yield peaked with 160 lb/acre K_2O, 100% RY (1660 cartons/acre), near the recommended rate of 150 lb/acre K_2O for low M-1 K soils. With K rates of 240 and 325 lb/acre K_2O, yields declined 8 and 12%, respectively. There were no significant differences in yield responses to K supplied from either KNO_3, KCl, or K_2SO_4 at either location.

A fifth study at Live Oak, spring 1990, was conducted on a soil testing 54 ppm for K and 100 lb/acre K_2O was recommended (Locascio et al., 1994; Locascio et al., 1997a). Yield increased through 160 lb/acre K_2O (2175 cartons/acre, 97% RY) and was unaffected by additional K_2O at 240 or 325 lb/acre. The recommended K rate at this site would have been insufficient for maximum tomato production. Yield response was not affected by K sources KNO_3, KCl, or K_2SO_4.

Research in Dade County was aimed at determining N and K fertigation rates for the Rockdale soils and evaluating N and K effects on graywall incidence (Carranza et al., 1996). Graywall and other ripening disorders are often associated by growers with low-K fertilization. Graywall is a particular concern in commercial fields as yield losses to graywall of 10 to 20% are common with occasional losses greater than 50%.

A factorial experiment was used with four N rates and four K rates from NH_4NO_3 and KCl, in a fall/winter 1995-1996 season (Carranza et al., 1996). Twenty percent of the fertilizer was applied and incorporated preplant and the remainder was injected through a drip irrigation line. Bed spacing was not indicated. Fertilizer injection graduated from 7 lb/acre/week N or K_2O through 14 lb/week after the fourth week in the season. Tensiometers were used to monitor soil moisture.

Soil samples sent to the IFAS Analytical Research Laboratory (ARL) resulted in medium- to high-K interpretations using the AB-DTPA soil analysis method (Soltanpour and Schwab, 1977). No yield response to applied K was anticipated and subsequent yield data confirmed no response to increased K (Carranza et al., 1996). The largest yield occurred with 50 lb/acre K_2O, 100% RY (1,743 cartons/acre) and the yield was 83% RY with zero lb/acre K_2O. Leaf tissue analysis results were not reported. Leaf-petiole sap K^+ concentrations averaged 3300 ppm, just below the 3500 to 4000 ppm recommended concentration (Hochmuth, 1994) at first flower. Potassium concentrations were adequate for the remaining three sample stages, but did not increase appreciably with K rates above the 50 lb/acre K_2O rate throughout the sampling periods. Low-K fertilization was not a factor in graywall incidence on this medium- to high-K soil. Additional K_2O at rates above 50 lb/acre had no effect on total marketable yield or graywall incidence.

The M-1 recommended K rate for drip-irrigated tomato was supported by high yields in three of five statewide studies. The recommended rate (100 lb/acre K_2O) was not evaluated at two of these three trials, higher rates (215 and 430 lb/acre K_2O) were applied instead. At the third trial, yields maximized above the recommended rate. Increases in K above the recommended rate did not generally increase yields, in one season, yields fell 12% with 325 lb/acre K_2O. Potassium absorption as measured by petiole sap testing indicated K concentrations did not increase with excess K application. Higher than recommended rates of K were not utilized by tomato for optimum growth or yield. Potassium sources, KCl, K_2SO_4, or KNO_3 did not affect yield response at any drip-irrigated site.

Potassium Summary

Potassium rate recommendations from 1989 consistently failed to optimize yields in 15 of the 18 trials reported above. Tomato yields responded near the new 1995 recommended K rate, based on M-1 soil test indices, in 70% of the trials documented above. Four subsurface-irrigated trials and one drip-irrigated trial accounted for the remaining 30% of trials that required greater K amounts for optimum yields. Winter conditions likely reduced absorption of applied K in two of the subsurface trials but, of greater significance were the large amounts of residual K fertilizer found in the band post-harvest. Band application of K fertilizer has proven the least efficient K application method with other vegetables. Based on results from these K trials, the recommended maximum K rate was increased in 1995 from 160 to 225 lb/acre K_2O. Yield data is graphed in Fig. 2 where the dashed line indicates the maximum IFAS recommended K rate for soils very low in M-1 K (225 lb/acre K_2O). Revised recommendations were from 160 to 225 lb/acre K_2O and from 130 to 150 lb/acre K_2O, for respective very low and low M-1 tested K soils (Kidder and Hochmuth., 1989; Hochmuth and Hanlon, 1995), based on some of the above summarized work. Where symbols overlap (Fig. 2), yield data confirm high yields of 94 to 100% RY to the left of the dashed line or with 240 lb/acre K_2O, (near 225 lb/acre K_2O). Potassium sources KCl, K_2SO_4, and KNO_3, had no effect on yields of drip or subsurface-irrigated tomatoes in all trials except one where tomato yields increased 19% with the KNO_3 treatment.

Summary

Applied fertilizers used in Florida tomato production averaged 310-200-540 lb/acre N - P_2O_5 - K_2O as surveyed by the Florida Agriculture Statistics Service for 1994 (Fla. Agr. Stat. Serv., 1995). These actual applied rates exceed IFAS current maximum recommendations of 175-150-225 lb/acre N, P_2O_5, K_2O, found through experiment to meet tomato requirements for high yields based on soils with very low P and K concentrations (Hochmuth and Hanlon, 1995). Mehlich-1 soil tests often result in low, medium, high, and very high indices of residual soil P and K and IFAS recommendations are further adjusted downward based on nutrient concentrations present in the soil. Assuming soils tested statewide were very low in P and K, 1994 applied fertilizers were 25 and 60% above the recommended rate for these nutrients and 45% above the recommendation for N fertilizer. Lower rates of applied fertilizer would reduce fertilizer costs without sacrificing yields (fertilizer costs: $305/acre. Smith and Taylor, 1996). When no additional P and K are required on soils high and very high in these nutrients, fertilizer costs and environmental impact could be reduced further.

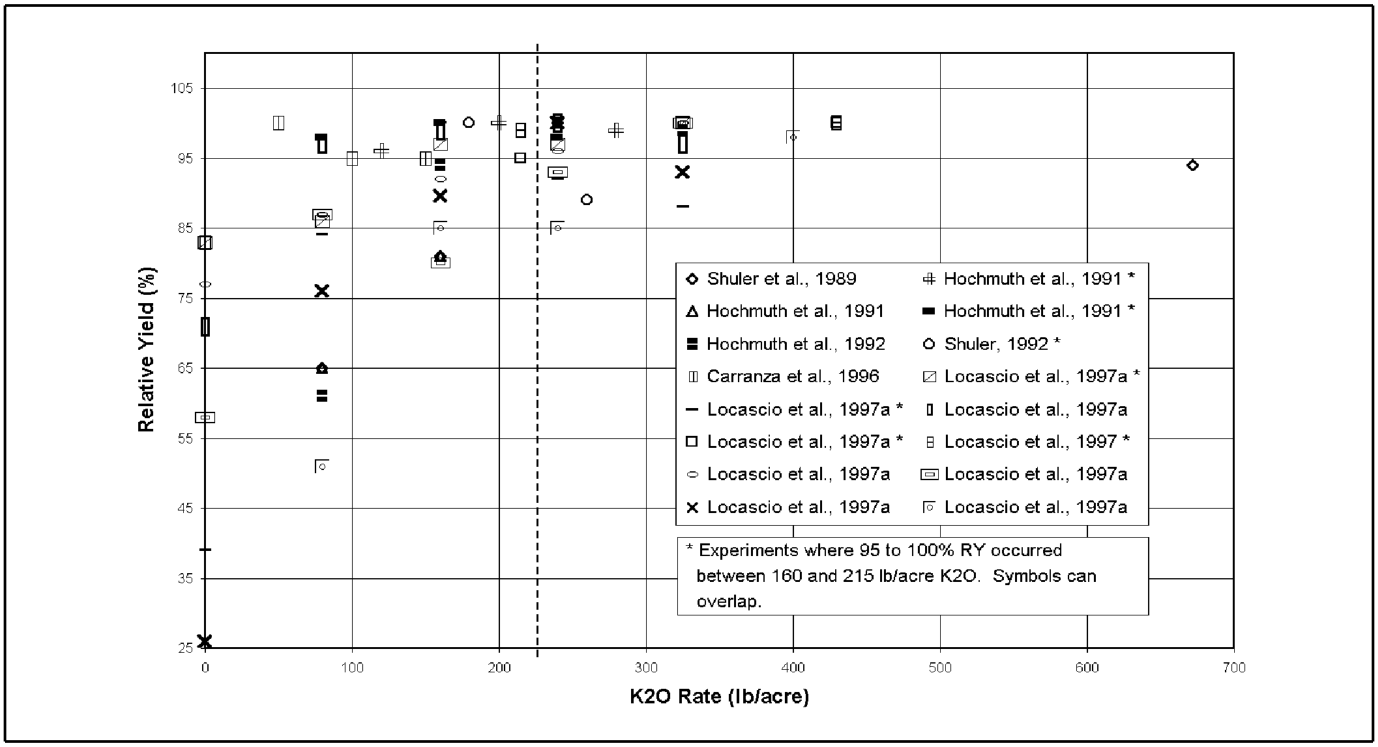

Figure 2. Relative yield of tomatoes for experiments, years, and seasons as a function of added K_2O.

Determination of the most yield-responsive fertilizer rate for tomato, improving fertilizer- plant efficiency, and reducing nutrient leaching losses have dominated research. Use of polyethylene mulched beds, coated fertilizers (polymer, resin, and sulfur-coating), split fertilizer applications, and restricted water application have focused on fertilizer application timed to plant needs without the N losses associated with excessive water and fertilizer application. In these studies, most tomato yields responded to applied fertilizer N up to 175 lb/acre N, with slightly less nutrient required with tomatoes grown on loamy soils compared to sandy soils.

The objective of increasing fertilizer efficiency was found in these studies to be partially accomplished by avoiding inefficient fertilizer placement methods, particularly band placement of K fertilizer under subsurface irrigation. Other means of increasing fertilizer efficiency include following calibrated soil test recommendations, managing irrigation in an optimal manner, and applying some of the N and K through the drip irrigation system.

Additional research is needed to improve the efficiency of the fertilizer-soil-plant system. Although drip irrigation has reduced water use by one-third to one-half of the water used in subsurface and overhead-irrigated fields, N and K remain of greatest concern as potentially leached fertilizer elements, even with this low water-use irrigation method. Research is needed with CRN and K sources, where a preplant only fertilizer application could reduce N leaching losses, reduce management costs associated with split fertilizer application and fertigation, and provide a sustained nutrient source. As new CR fertilizer sources are developed, experimentation will be needed to determine their effectiveness with specific crops. Improvement remains possible with fertilizer sources that adjust to seasonal growing conditions, spring, fall, and winter crop periods where temperatures, soil microbial activity, and plant growth rate change. Where soil N retention is poor, increasing organic matter content with cover cropping or otherwise, is known to increase N mineralization and decrease the need for applied fertilizer N. Studies also are needed on optimal timing of N application with drip irrigation systems and on the fate of N in the soil system as it relates to N and irrigation management. Large-scale demonstrations on commercial farms of recommended nutrient management programs are also needed.

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