HS753

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

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Bell-pepper production in Florida during the 1996-1997 season, from 19,000 harvested acres, resulted in 23 million 28-lb cartons valued at $230,925,000. The largest volume of Florida pepper production came from the southwest, 36%, then southeast, 38%, central, 24%, and north, 3% (Fla. Dept. of Agr. and Cons. Serv., 1998). Fertilizer costs averaged $315/acre for a total of $6.6 million over a total planted area of 21,000 acres (Smith and Taylor, 1996). Survey findings for Florida chemical usage, 1994, reportedan average 285-139-393 lb/acre N-P_2O_5-K_2O were fertilized on green-pepper fields (Fla. Agr. Statistics Serv., 1995). These averaged rates exceeded the IFAS recommended N rate of 175 lb/acre, were near the maximum P_2O_5 recommendation, and more than double the maximum 160 lb/acre K_2O recommended rate (Hochmuth and Hanlon, 1995). Although fertilizer costs typically are only 5% of total preharvest costs, excess fertilizer application poses a negative environmental risk and reduces profitability.

More than forty years of pepper fertilization research has been conducted in Florida. During this time many changes have occurred in pepper production practices including changes in cultivars and introduction of new cultural systems including polyethylene mulch and drip irrigation. The purpose of this publication is to summarize pepper fertilization research, document the research behind current University of Florida recommendations for pepper fertilization, and to point out needs for more research. Since nutrient and water management are linked, fertilization research is summarized by irrigation method.

Data Summary Method

Evaluation of pepper yield responses to variable rates of applied fertilizer required a standardized method of summarizing statewide yields expressed variably as bushels, cartons, boxes, or tons/acre. In addition, vegetable yields can vary depending on season, cultivar, and location in the state. Relative yield (RY), a calculated percentage, was chosen as the unit to express pepper yield responses to fertilization. The highest yield for each fertilizer experiment was designated as 100%, and other yields were expressed as a percentage of the highest yield. The actual yield in 28 lb cartons was presented for the

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treatment corresponding to 100% RY. The RYs were plotted against rates of nutrient to determine how pepper yields responded to fertilizer in Florida. The RY presentation allowed data from a variety of experiments to be included in the summary of yield responses to fertilization. For most studies, RYs of 95 to 100% were not significantly different from each other.

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 of a 6-foot-bed-spacing crop as in the bed of a 4-foot-bed-spacing crop requires 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 (1996b). Fertilizer-rate expressions used in this summary and its figures are those rates presented by the various authors in their research papers. Most authors express rates on a per-acre basis, irrespective of variations in bed spacings among reports or experiments. Authors of a few reports choose 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

Overhead Irrigation

The effects of increasing N rates, defloration, and defruiting treatments on growth and yield of overhead-irrigated, unmulched pepper were evaluated in two experiments (Singh and Nettles, 1961). In a 1960 experiment 40-180-66 lb/acre N-P_2O_5-K_2O were banded to each side of the row and beneath the soil at transplanting and again 30 days later. Supplements of sodium nitrate were side-dressed at 30-day intervals to achieve total N rates of 100, 150, or 200 lb/acre. In 1961, 40-180-66 lb/acre N-P_2O_5-K_2O were applied as before, but at transplanting only. Side-dressings of sodium nitrate were applied for total N rates of 50, 100, or 150 lb/acre. Rows were spaced 34 inches apart.

Increasing N from 100 to 200 lb/acre decreased marketable yields in 1960 from 100% RY (300 cartons/acre) to 81% RY, respectively, with yields averaged over defloration and defruiting treatments. Researchers cited increased rainfall and N leaching losses in the 1960 yield decline. Yield was optimized with 100 to 150 lb/acre N. Blossom-end rot increased with increased N.

Overhead irrigation was used on a Dover pepper field where varying rates of N fertilizer were applied in the 1970 and 1971 seasons (Albregts, 1971). Initial soil nitrate-N concentrations were chemically determined from water extracts taken at field capacity. The results were 337 and 101 ppm in 1970 and 1971, respectively. Soils were Scranton fine sand with 4% organic matter. One-third of the fertilizer was broadcast and the remainder banded at the bed center. Beds were spaced 56 inches apart. Nitrogen rates were 0, 80, 160, or 240 lb/acre and resulted in quadratic RY responses of 18, 73, 100 (908 cartons/acre) and 92% for each respective N rate. Second-year applications of 0, 100, 200, and 300 lb/acre N resulted in quadratic RY responses of 22, 69, 97, and 100% (725 cartons/acre) for each respective N rate. Optimum yield response was with the 160 to 240 lb/acre N fertilization rates. Paper mulch was used on beds in this study.

Work with biodegradable polyethylene-coated paper mulch and two different N rates in two years was conducted on okra and pepper crops in Dover (Albregts and Howard, 1973). Bed spacing was not indicated in this study. In spring 1971, RY responses to 160 and 212 lb/acre N were 92 and 100% (556 cartons/acre), respectively. These yields were not significantly different. In spring 1972, RY responses to 200 and 400 lb/acre N were 87 and 100% (547 cartons/acre), respectively, significant at the 5% level. High rates of residual NO_3, 685 and 395 ppm, were extracted with saturated water extract from mulched beds prior to the last unmulched fertilization each year. Average yields of mulched pepper were double the average yields of unmulched peppers (507 and 258 cartons/acre, respectively), and average fruit weight was 15% higher with mulched than with unmulched pepper.

In experiments over four seasons at Gainesville, 1972-1975, black polyethylene mulch was used on some trials and not others and fertilizer placement was varied between broadcast, band, and multiple band applications (Locascio and Fiskell, 1977). Yield responses to three N rates were averaged over these treatments. Plots were 6 x 25 feet with two rows per plot. The largest yield response occurred between 50 and 125 lb/acre N in 1973. Quadratic yield responses resulted, and yields leveled off between 125 lb/acre N (91% RY) and 200 lb/acre N (100% RY, 534 cartons/acre). An interaction, significant at the 1% level, occurred between fertilizer placement and rate in 1972. Yield was affected differently by increasing N rates with each placement method. Linear yield responses resulted with mulched/broadcast-fertilized pepper. Quadratic yield responses resulted with unmulched/broadcast-fertilized pepper. Linear yield responses occurred when unmulched pepper received a single banded fertilizer application, and yields were not affected when fertilizer was applied in three broadcast applications to unmulched pepper. Overall yields were progressively higher in 1974 and 1975 compared to 1973 yields. Yield responses were not different in 1974, producing an average 663 cartons/acre with N rates from 125 to 275 lb/acre. In 1975, yields responded quadratically, significantly at the 10% level, reaching optimum 100% RY (890 cartons/acre) with 200 lb/acre N and declining to 89% RY with 275 lb/acre N. Results from three seasons suggested that the N fertilizer requirement of pepper was about 200 lb/acre. Leaf N concentrations of about 4% were associated with highest yields.

A factorial study of 12 N sources, three N rates, and applied in banded or broadcast applications with three forms of mulch was conducted near Gainesville over two seasons, 1972 and 1973 (Locascio and Fiskell, 1979). Plots were 6 x 25 feet, and fertilizer was aplied in a five-foot area across the bed center. Although no statistics were provided with each N source, placement, and mulch treatment, visual inspection of the data showed yields with some N sources increased with higher N rates, but yields with other N sources did not. The author cited lower yields from plants fertilized with 200 lb/acre N of soluble urea or sulfur-coated urea (SCUslow dissolution rate, 20%/week) when both were broadcast and unmulched. Yields with all other N sources increased linearly through the 200 lb/acre N rate. Over both years, highest yields were produced with broadcast SCUs (faster dissolution rates: 30, 35, and 44%/week), urea broadcast in three applications, and urea broadcast under mulch. Lowest yields were obtained with banded urea, urea with 10-inch-wide polyethylene strip mulch and broadcast urea-formaldehyde. The author cautioned against band application of urea due to soluble-salt injury with increased N rates.

Evaluation of soil N in this experiment indicated N retention was equal or better with polyethylene mulch over broadcast or banded fertilizer compared to unmulched multiple fertilizer applications/season or controlled-release (CR) N forms. On unmulched soil, CR-SCU and isobutylidene diurea (IBDU) provided assurance of adequate soil N. Relative yield responses to N rates of 50, 125, and 200 lb/acre were 48, 88, and 100% (592 cartons/acre), respectively in 1972, and 65, 90, and 100% (534 cartons/acre), respectively in 1973. Maximum yields in both years occurred with 200 lb/acre N.

The results of Gainesville experiments conducted in 1974 and 1976 closely paralleled the previous study (Locascio et al., 1981). Plots were 6 x 25 feet and were planted in double rows. A significant interaction (5% level) occurred between N rate, N source, and placement in 1974. Soluble-salt injury likely caused a sharp decline in marketable yields with broadcast NH_4NO_3 between N rates of 200 (1000 cartons/acre) and 275 lb/acre (571 cartons/acre). Lower N rates, 125 to 200 lb/acre, reduced marketable yields of banded NH_4NO_3 (715 to 534 cartons/acre) and urea-formaldehyde (607 to 357 cartons/acre). In 1976, a significant interaction (5% level) occurred between N rate, N source, and mulch. Mulched plants with $(NH_4)_2SO_4$, urea, and SCU-2 (26.8% dissolution in seven days) reached peak yields with 125 lb/acre N, and unmulched plants treated with $(NH_4)_2SO_4$, urea, and NH_4NO_3 reached peak yields with 125 lb/acre N. In this season fertilizers were broadcast: once at preplant with the mulched treatments and in three equal applications with the unmulched treatments. The above research suggested that peppers with proper water management practices were unlikely to respond to soluble N sources in one application under mulch at rates above 125 lb/acre N. Higher soluble N rates risked soluble-salt injury.

Due to the interactions in both seasons, yield response to N rate was presented in Fig.1 for each N source. Peppers grown with controlled-release N sources responded to N rates up to 275 lb/acre supplied from IBDU, SCU (32% dissolution in seven days), and urea-formaldehyde, when broadcast, incorporated, and mulched, but failed to respond when N was banded and mulched (1974). Pepper yields, with and without mulch in spring 1976, were highest with CR-N sources: IBDU and SCU-1 and -3 (37 and 32% dissolution in 7 days) with the 200 lb/acre N rate (275 lb/acre N were not tested). Of the soluble N sources, NH_4NO_3 alone resulted in peak yields with 200 lb/acre N when mulched. With CR sources, more efficient utilization of N may have resulted in yield increases with N rates above 125 lb/acre. A long six-harvest season likely resulted in the yield response to 275 lb/acre N CR-N.

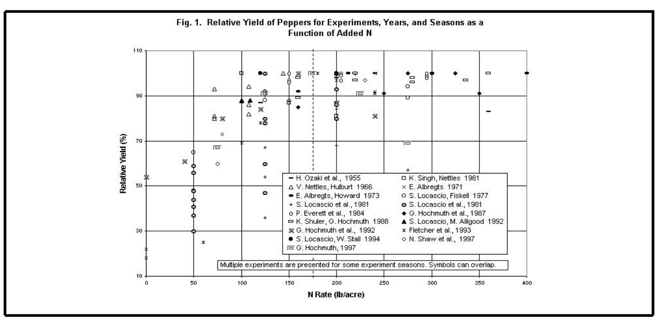

Fig.1.

Mulch use increased pepper yields 25% over yields from unmulched trials in 1976 (significant at 1% level). Yield results were averaged over three N rates, 50, 125, or 200 lb/acre, and were higher with all N sources for mulched pepper compared to unmulched. Soil N retention with the mulched planting was 70% higher three and 15 weeks after fertilization due to reduced leaching of soluble nutrients with polyethylene mulch in these overhead-irrigated fields.

An overhead-irrigated and mulched pepper crop near Gainesville responded equally to N rates of 120 or 200 lb/acre N (Locascio and Stall, 1994). The soil, previously uncultivated, had 1.7% organic matter which was credited with equalizing the response to N. Nitrogen sources, IBDU, 35% of total N, and NH_4NO_3, 65% of total N, were blended, broadcast, incorporated, and mulched with black polyethylene.

Subsurface Irrigation

Three rates of N and three rates of K were evaluated in a factorial study on Davie fine sand near Fort Lauderdale (Ozaki et al., 1955). The study occurred over the 1953-1954 and 1954-1955 growing seasons on subsurface-irrigated fields with a constant two-foot water table. Beds were planted in double rows, but the bed spacing was not indicated in this study. Pepper yields produced with N rates of 100, 200, and 300 lb/acre were 87, 98, and 100% RY (757 cartons/acre), respectively. Yields with between 200 and 300 lb/acre N were not different. Frequent, adequate rainfall was cited for the 1953-1954 season and leaching was suspected. In the second season, yield responses were also not different between 120 and 240 lb/acre N (87 and 100% RY [612 cartons/acre], respectively). Through use of regression analysis, researchers indicated that RY fell to 83% with 360 lb/acre N. Injured fruits, white tissue drying to brown, were present on plants with all treatments this year. Numbers of injured fruits were greatest with the highest N and K rates. Associated increases in fruit injury with higher N rates were noted in earlier research by Singh and Nettles (1961), supporting 200 lb/acre N as the optimum N rate for overhead-irrigated and nonmulched pepper.

A subsurface-irrigated, mulched study in Immokalee established controlled-release (CR) fertilizer as a useful starter fertilizer to prevent seedling burn and to hold nutrients during wet seasons (Everett, 1977). Starter fertilizer sources alone were tested in fall 1976 including Osmocote (15-5-21 [N-P_2O_5-K_2O]) and a 50% Osmocote blend (10-12-11 [N-P_2O_5-K_2O]). Controlled-release N sources were banded two inches below the row, two inches below and to the side of the row, or in a four-inch band in the plant row. Nitrogen rates were 0, 30, 60, or 90 lb/acre. A soluble fertilizer, 18-0-25

($N-P_2O_5-K_2O$), broadcast two feet across the row at 36 lb/acre N was also tested. At one and two weeks after transplanting, soluble salts from soluble fertilizer sources had leached from the upper two inches of soil to the same soluble-salt concentrations as with unfertilized soil. Five weeks after transplanting, a perched water table had driven salt concentrations in the soil treated with the soluble fertilizer source to 1.7 times higher than the Osmocote-treated soils. Both the straight Osmocote and the blended form resulted in less leaching and reduced surface-salt accumulation compared to the soluble N source (KNO_3 and NH_4NO_3).

In the spring 1977 season, the above starter fertilizers (Osmocote, Osmocote blend, and the soluble source) were tested at rates of 0, 30, or 60 lb/acre N. Additional soluble fertilizer at 180 lb/acre N was banded on both sides of the starter-fertilized beds. A higher N rate was applied on the zero-starter-fertilizer treatment. Relative yield responses with 0, 30, or 60 lb/acre (starter) N were 83, 100 (1147 cartons/acre), and 97%, respectively. Controlled-release starter fertilizer at 30 lb/acre N proved a worthwhile starter N source at this early stage of pepper growth.

Relative yields were not affected by simultaneous changes in both N and K rates over three Immokalee trial seasons: spring 1982, fall 1982, and fall 1983. Relative yields of 96 to 100% (1459, 1311, and 1300 cartons/acre, respectively) resulted from 150 lb/acre N and 210 lb/acre K_2O. Yield responses with 205 lb/acre N (290 lb/acre K_2O) and 295 lb N, (415 lb/acre K_2O) did not vary from yields with the lower N and K rate in this mixed N and K study. Spring plantings were mulched with black, and fall plantings, with white polyethylene. Nitrogen at 25 lb/acre was applied preplant to a low bed then covered with four inches of soil, with additional N from KNO_3 and NH_4NO_3 (70% NO_3-N, 30% NH_4-N) applied in two shoulder bands. Despite a long harvest season and high rainfall over the three trial periods, N and K programs supplying 150 lb/acre N and 210 lb/acre K_2O proved sufficient for optimum yields.

Researchers at subsurface irrigated, sites in Martin, Manatee, and Palm Beach counties (Hochmuth et al., 1987a) tested two N rates each, using SCU at Martin County and mixed fertilizer sources at the remaining counties. Beds were spaced 6 feet on center. At Martin County, 120 lb/acre N (SCU) were broadcast and incorporated preplant, and additional N was banded outside of the plant rows for a total of 275 or 350 lb/acre N. The highest yield, 100% RY (1263 cartons/acre), occurred with 275 lb/acre N. Yield dropped 10% with the 350 lb/acre rate.

At Manatee and Palm Beach counties, 24 and 25 lb/acre N, respectively, of mixed fertilizer were incorporated in the bed at preplant. The remaining fertilizer was banded on the bed surface for total N rates of 160 and 220 lb/acre at Manatee County and 250 and 325 lb/acre N at Palm Beach County. Relative yields at Manatee County were 85 and 100% (1355 cartons/acre) with each N rate. Overall, yields in the Palm Beach County study were 40% lower than yields achieved at either Martin or Manatee counties, resulting in 100% RY (810 cartons/acre) with 325 lb/acre N. Researchers cited a drastic lowering of the water table at the Palm Beach trial during weeks five through eight. Heightened end-of-season soluble-salt levels of 1300-1700 ppm (with 250 and 325 lb/acre N, respectively) were attributed to this dry period leading to subsequent soluble-salt injury and reduction in yield. Soil at all sites had comparable prefertilization soil soluble-salt levels of 100 to 200 ppm.

Total N rates of 160, 220, 280, or 360 lb/acre were compared for effects on pepper production at a Jupiter spring planting (Shuler and Hochmuth, 1988b). Experimental plots were 6 x 20 feet and planted with two rows per bed. Sulfur-coated urea was broadcast at 120 lb/acre N, with the remainder of each rate applied in a band on the bed surface or two inches below the surface. Relative yields ranged from 89, 97, 96, and 100% (1380 cartons/acre) with each N rate noted above. Yield statistics were not given with this report.

In a winter study on a commercial pepper farm in Boynton Beach (Shuler and Hochmuth, 1988a), peppers planted on 6 x 20-foot plots did not respond to increased N rates above 160 lb/acre (98% RY), the recommended N rate in 1989 (Hochmuth and Hanlon, 1989). Additional N to 220 lb/acre increased RY 2%

(1535 cartons/acre). Based on these results, the current (1995) IFAS recommendations of 175 lb/acre N would be adequate for optimum pepper yields, even for this six-harvest season. Nitrogen applications at twice the recommended amount, 360 lb/acre applied to the growers field, provided no yield benefit over the 160 lb rate. In this study, all fertilizer treatments were applied in two side bands and one center band.

A subirrigated pepper study in Bradenton (Stanley and Clark, 1993) was designed to determine how much N leached out of the root zone, how much N was utilized by the crop, and how much water was utilized by the crop in a four-month growth cycle. Units were constructed of four separate plastic barrels linked by valves to one sump. A lysimeter controlled the irrigation and drainage to maintain water levels at 18 to 20 inches for two plants per subunit (eight per lysimeter). Soil within the containers was leached to minimal N concentrations, and KNO_3 + NH_4NO_3 were applied at 300 lb/acre N. Fertilizer was placed eight inches from the plants in 12 inch bands, 1.5 inches deep, and the soil surface was covered with black polyethylene. The total N content was determined from harvested fruit and from vegetative tissue taken at the end of the season. Plant tissue, residual soil, and unaccounted-for N were itemized as follows, 51.9% N (156 lb/acre), 25% (75 lb/acre), and 23% (70 lb/acre), respectively. Plant N uptake confirmed current N recommendations of 160-175 lb/acre for pepper (Hochmuth et al.,1988; Hochmuth and Hanlon, 1995). The sustained high water table prevented N loss from leaching, but denitrification or loss of N to the atmosphere was suspected for the 23% lost N.

Drip Irrigation

Research of drip-irrigated pepper was limited to five published studies. A Suwannee Valley Research and Education Center spring planting tested NH_4NO_3 applications of 0, 40, 80, 120, 160, 200, and 240 lb/acre on mulched beds (Hochmuth et al., 1992a). Fertilizer was hand applied and incorporated with a rolling cultivator on beds spaced on 5-foot centers. Total marketable yields increased quadratically in response to increasing N rate. Rates in excess of 160 lb/acre N (100% RY, 700 cartons/acre) had a negative effect on total marketable yield.

The second study was a 2 x 10 factorial experiment at the UF Horticulture Unit near Gainesville (Locascio and Alligood, 1992). Two N rates, 100 and 200 lb/acre, and 10 soluble and CR sources of N and K were compared. The N and K sources were broadcast 40% preplant (KCl, NH_4NO_3, and $Ca(NO_3)$) with 60% drip applied (NH_4NO_3, $Ca(NO_3)$, and KCl) once per week for 10 weeks. A second treatment involved broadcast of KNO_3, 100% at preplant. Single beds, 4 x 24 feet, were polyethylene mulched, and peppers were irrigated at 0.75 times pan evaporation.

Highest total yield was produced with the preplant KNO_3-NH_4NO_3 treatment, intermediate yields with NH_4NO_3 and coated KNO_3-CR urea treatments, and slightly lower yields with remaining N sources. All yields exceeded state average yields, though higher yielding treatments also led to higher soil NO_3-N concentrations later in the season. One hundred percent RY (1095 cartons/acre) were achieved with the 200 lb/acre N rate, and 88% RY with 100 lb/acre N.

Nitrogen fertilization experiments with pepper were conducted in Live Oak at the Suwannee Valley Research and Education Center (SVREC) on Lakeland fine sand, in spring 1992 (Fletcher et al., 1993). Research to calibrate petiole-sap N concentrations was sought for drip-irrigated and polyethylene-mulched peppers. Nitrogen treatments ranged from 60 to 240 lb/acre NH_4NO_3-N with treatments increased in increments of 60 lb/acre. Potassium was applied uniformly at 130 lb/acre K_2O (KCl), and no phosphorus (P) was applied due to high soil-test P concentrations. Tilled soils received fertilizer treatments in a 36-inch-wide band which was incorporated and formed into beds on 5-foot centers. The N recommendation for pepper at the time of this study (Kidder et al., 1989) was 160 lb/acre, based on a 6-foot row spacing (190 lb/acre for rows 5 feet apart).

Marketable fruit yields, composed mostly of U.S. No. 1 and fancy-grade fruits, responded quadratically (5% probability) through 180 lb/acre N (814 cartons/acre, 100% RYcarton weight not specified). Using the quadratic equation, yield maximized with 190 lb/acre N (810 cartons/acre) as recommended ($r^2 = 0.76$). Leaf-tissue N concentrations below the critical range occurred with N treatments of 60 lb/acre (early harvest) and with 60 and 120 lb/acre (final harvest). Leaf-tissue N concentrations were above critical concentrations with all other N treatments. Petiole-sap concentrations with the optimum 180 lb/acre N treatment were 1500 ppm (prior to blossom), 800 ppm (early harvest), and 500 ppm (2nd harvest).

Nitrogen fertigation trials were conducted at the University of Florida Horticulture Research Unit, Gainesville, in 1995 (Shaw et al., 1997). Ammonium nitrate was broadcast and incorporated preplant at 0, 30, 70, and 100% of the total season applied N rates of 75, 150, 230, and 300 lb/acre N. Potassium magnesium sulfate was also broadcast preplant at 20% of the recommended K_2O rate. Based on M-1 soil tests, no P and 130 lb/acre K_2O were recommended. Remaining N and K_2O (NH_4NO_3 and KNO_3) were fertigated at equal rates for twelve weeks. Two-foot-wide beds were set on 6-foot centers with two plant rows per bed (28,550 plants/acre). Irrigation was applied to keep soil moisture between -5 and -15 cb, as measured by a tensiometer.

At higher percentages of preplant-applied N, total marketable yield decreased quadratically. Peak yields occurred with 30% preplant N. Highest marketable yield response, 100% RY, occurred with 300 lb/acre N, producing 694 cartons/acre. Yield responses were modeled with quadratic and linear-plateau equations. Taking a midpoint value between maximum N rates of each model indicated 215 lb/acre N were sufficient for high yields, near the 230 lb/acre N rate (97% RY). Whole-leaf N concentrations were above the sufficient range throughout the season (> 4.0%). Incidence of BER increased nine times (3.5 to 36 cartons/acre) with N rates between 75 and 300 lb/acre.

In drip-irrigated experiments summarized above, 0 to 100% of the preplant-applied fertilizer were derived from a soluble or a soluble plus CR fertilizer. The portion of fertilizer not applied at preplant was applied through the drip line throughout the season. A fourth experiment tested the yield responses of pepper to two CR-Meister fertilizers (Hochmuth, 1997). Each fertilizer was applied entirely at preplant in a 10-inch-wide band on the bed surface. Beds were spaced on 4-foot centers, and N rates were 75, 125, 175, 225, and 275 lb/acre N. The mixed N-P-K Meister fertilizers were 15-5-15 (N-P_2O_5-K_2O) and 19-5-14 (N-P_2O_5-K_2O); each was polymer-coated. Fertilizer placement methods were evaluated by additional trials of broadcast/incorporated NH_4NO_3 or CR-Meister 15-5-15 (N-P_2O_5-K_2O), applied preplant at 175 lb/acre N. A zero-fertilizer check treatment was also included. The fall experiment occurred near Gainesville on Arredondo fine sand. Beds were mulched with white-on-black polyethylene and drip irrigated to maintain soil moisture at -10 centibars using tensiometers.

Total pepper yields peaked quadratically with 175 lb/acre N (100% RY, 1079 cartons/acre). Yield response was based on regression analysis of average yields from CR-Meister fertilizers applied on the bed surface. With 175 lb/acre N, yield response was 25% higher (1200 cartons/acre) when CR-Meister 15-5-15 (N-P_2O_5-K_2O) was broadcast and incorporated than when the same fertilizer was applied to the bed surface. Broadcast/incorporated NH_4NO_3 resulted in yields 40% lower (730 cartons/acre) than the CR-Meister treatment above. Yields declined with 225 and 275 lb/acre N to 91 and 69% RY, respectively, with the surface-applied CR fertilizers. Total fruit yields or total extra-large fruit yields were not different with either CR-Meister fertilizer, but early yield of extra-large fruit was highest with 125 lb/acre CR-N or with 175 lb/acre soluble N. Leaf-tissue N concentrations were well above sufficiency at bloom and first harvest with all N treatments.

Nitrogen Summary

Research with N fertilization of pepper spans more than 40 years from many production areas under three major methods of irrigation. Results of these studies are presented in Fig. 1, where the current N recommendation of 175 lb/acre N is highlighted by the vertical line. The graphical summary shows that pepper yield response to N fertilization levels off after the 175 lb/acre N rate. Plant leaf or petiole-sap testing results can guide the replacement of N leached by excessive rainfall or irrigation.

Yields with overhead-irrigated pepper responded positively to N fertilization up to 200 lb/acre N in most studies. Mulched, broadcast, and incorporated preplant N fertilizer proved the most efficient application method for pepper N uptake (except N sources: urea, $(NH_4)_2SO_4$, and SCU20% dilution in seven days, in amounts greater than 125 lb/acre N). Mulched pepper yielded 25% more than unmulched pepper. Overhead-irrigated, mulched soils also retained 70% of the applied N three and fifteen weeks after planting. Band application proved the poorest placement method for NH_4NO_3 in amounts greater than 200 lb/acre N, and $(NH_4)_2SO_4$ in amounts greater than 125 lb/acre N caused soluble-salt injury at higher N rates. Best yields often occurred when a portion of the N was supplied from a CR source.

Subsurface-irrigated pepper responded to N fertilization in the range of 150 to 275 lb/acre N. Results in most studies showed that N at 200 lb/acre, slightly above the current 175 lb/acre N IFAS recommendation, was adequate for optimum yields. At N rates above 275 lb/acre, yields were reduced. Yield responses to N fertilization of subirrigated pepper were similar for eastern (Palm Beach County) and west coast (Manatee) production sites.

More work is needed to better define effects of N management on soil and groundwater N concentrations. Research is needed to define the most efficient and environmentally safe management techniques to apply N with emphasis on soluble-N application timing, N fertigation, and CR sources.

Phosphorus and Potassium

Soil Testing

Knowledge of soil nutrient levels, particularly phosphorus (P) and potassium (K), before planting is the starting point to predicting pepper response to varying rates of applied P and K. Using soil testing to determine preplant soil nutrient levels provides information so research results may be reviewed for support of existing fertilization recommendations. The Mehlich-1 (double-acid) solution is the current extractant used by Florida and several other southeastern U.S. 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 and Hanlon, 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, but review of research results from studies with these extractants presents a profile of pepper response under varying fertilization conditions. This review also summarizes practices in water management, fertilizer application methods, fertilizer source, and the effect of mulch in the nutrient management system.

Phosphorus

Relatively few studies have been reported concerning P requirements of pepper. Current P recommendations for pepper are based on M-1 soil-test results. IFAS Standardized Fertilization Recommendations for Vegetable Crops (Hochmuth and Hanlon, 1995) provides five rating levels for soil P content from very low to very high. Recommended application rates in lb/acre P_2O_5 are given for each rating level. Soils testing high and very high in P require no P fertilization. Yield results from a Live Oak study (Hochmuth et al., 1992b) support this recommendation, with an optimum RY of 95% (712 cartons/acre) with 0 lb/acre P_2O_5. Addition of 50 or 100 lb/acre P_2O_5 did not improve the yield, quality, or grade of peppers at this site testing high in M-1 P.

Fine-sand soils, in an early study on the lower east coast of Florida, contained water-extractable P concentrations ranging from trace levels to 2 ppm (Ozaki and Hortenstine, 1962). Phosphorus application of 50 lb/acre P_2O_5 doubled the yield over the check (zero P) treatment, while additional P at 100 lb/acre P_2O_5 gave no additional yield response (68-inch beds). Side-dressing half of the P during the growing season did not increase yields over banding all of the P at planting. Plants with all treatments, including the check treatment, had above 0.3% leaf-tissue P concentrations. Leaf-tissue concentrations above 0.3% are considered adequate for leaf tissue sampled at first blossom, early fruit set, and early harvest. Plants with zero P, however, were slow to mature, had less vegetative growth, and yielded 45% less than P-treated plants.

A Mehlich-1 extractable P index of 18 lb/acre (9 ppm) reported in an N and K subsurface-irrigated pepper study was interpreted as very low for pepper production (Everett and Subramanya, 1983). For this experiment on Immokalee fine sand, 240 lb/acre P_2O_5 were added with excellent yield results (1375 cartons/acre, average yield over three seasons and three N rates). Beds were spaced on 6-foot centers. Current IFAS standardized pepper recommendations, based on M-1 soil-index values, predict that 160 lb/acre P_2O_5 would have been needed in this case for optimum growth.

Phosphorus fertilizer sources used with fertigation systems were limited by cost, tendency to bind with Ca and Mg in the water source and clog emitters, and by their immobility away from the emmitter once applied (Csizinszky, 1997). Availability of a fully water-soluble monopotassium phosphate (KH_2PO_4) prompted experiments to evaluate bell-pepper response to ratios of dry P, applied preplant, and to soluble injected P. Experiments were conducted in Bradenton, Gulf Coast Research and Education Center, on EauGallie fine sand soils, fall 1994 and spring 1995. Soil P concentrations, extracted using M-1, were considered medium (21 ppm), and 100 lb/acre P_2O_5 were recommended (Hochmuth and Hanlon, 1995). Dry fertilizer sources, NH_4NO_3 (85 lb/acre N) and K_2SO_4 were applied preplant in a band above the irrigation tube. Additional N and K were injected as NH_4NO_3, KNO_3, and KH_2PO_4. Total N applied to all treatmets was 260 lb/acre. Phosphorus treatments included P rates of 0, 106, or 213 lb/acre P_2O_5 from either dry or liquid P sources, or a combination of both. With the 106 lb/acre P_2O_5 treatment, P was applied all preplant in an 8-inch-wide band before bedmaking as either 33% preplant (superphosphate) and 67% liquid injected (KH_2PO_4), or 100% liquid injected (KH_2PO_4). A fourth treatment was 213 lb/acre P_2O_5 (superphosphate) applied preplant. Beds were spaced on 5-foot centers and mulched with white-on-black polyethylene in the fall and black polyethylene in the spring. Soil moisture concentrations were maintained with tensiometers.

Marketable yields did not respond to P fertilization rates, time of application (preplant or injected), or P source in either experiment season. Yield of fancy-grade fruit was decreased with P fertilization in the fall 1994 season. Researchers noted that the demand for P was greatest early in the growing season and that application thereafter may only have been effective to correct late-developing P deficiency symptoms. Researchers concluded that no P was needed for optimum pepper yields where soils tested 21 ppm (current recommendations are for 100 lb/acre P_2O_5). Yields in the fall of 1994 were above the west central Florida average yield of 666 cartons/acre with an average of 1047 cartons/acre for all P treatments that season. Yields in the spring of 1995 were below the average regional yield of 911 cartons/acre with an average of 663 cartons/acre.

Potassium

Overhead Irrigation

The overhead irrigation studies presented here predate the use of M-1 extractant for K; therefore only changes in yield response are measured against increases in applied K.

For pepper mulched with polyethylene-coated paper at Dover, Florida (Albregts, 1971), the best yield in 1970 was achieved with 160 lb/acre K_2O. One-third of the fertilizer was incorporated, and the remainder banded, in the bed center; rows were 56 inches apart. A 79% RY (574 cartons/acre) was produced without fertilizer on this site which contained 102 ppm water-extractable K. The following year, K had depleted to 16 ppm (measured with water-extractant method), and 200 lb/acre K_2O were required to produce 97% RY (644 cartons/acre).

For overhead-irrigated, mulched pepper, yield appeared to peak with 200 lb/acre K_2O, thereafter declining as K_2O rate was increased to 360 lb/acre. Current IFAS recommendations are for 160 lb/acre K_2O on soils testing low in K. Results from this mulched crop indicate favorable yield responses with successive annual crops when one-third of the fertilizer is incorporated and two-thirds are banded preplant at bed center preplant with K_2O rates of 160 to 200 lb/acre for each season.

Subsurface Irrigation

Crop response to increasing rates of N and K fertilizer was measured for two seasons in an unmulched factorial experiment at Plantation Field Lab near Ft. Lauderdale (Ozaki et al., 1955). The water table was maintained two feet below the bed surface, and N and K were applied in five equal monthly applications. Row spacing was not indicated in this study, but plants within the row were 12 inches apart. Relative yield of fancy plus No. 1 grade peppers increased significantly in 1953-1954 with increasing K_2O from 100 to 200 lb/acre, 66% to 94% RY (796 cartons/acre), respectively. Relative yield did not increase significantly when K_2O rates were increased to 300 lb/acre (100% RY). In the second season, 1954-1955, plants were thinned to 9 inches, and RY responses of fancy fruit were not different: 96, 94, and 100% RY (572 cartons/acre) with K_2O rates of 120, 240, and 360 lb/acre, respectively. Yields were generally down from the previous year due to a dry second season. A shortage of available moisture during this dry season caused salts to accumulate at the surface, leading to soluble-salt injury.

Nitrogen and K rates from 50 to 1800 lb/acre were evaluated in an early N and K "ratio" study (Iley and Ozaki, 1966). Subirrigated beds were fertilized with 30-500-30 lb/acre N-P_2O_5-K_2O which were broadcast and incorporated preplant. Additional N and K fertilizers were banded between rows for a total N application of 300 lb/acre and total K rates of 50, 300, 900, and 1800 lb/acre K_2O. Beds were mulched with polyethylene. Best yields occurred with 300 lb/acre K_2O, 99% RY (70 lb fancy and U.S. No. 1 fruit/20 x 5.5-foot double-row plot). Potassium treatments between 50 and 300 lb/acre K_2O were not included, making this study incomplete for rates nearer the current recommended K rates.

Fields in three south Florida counties, Manatee, Martin, and Palm Beach, were used in a 1987 K study (Hochmuth et al., 1987a, 1990, and 1993). The fields tested low, 23 to 24 ppm, for M-1-extracted K, and 130 lb/acre K_2O were recommended. There were five fertilizer treatments in each experiment. Part of the fertilizer was broadcast and incorporated, and the remaining K was banded in single, double, or triple bands, depending on experiment. All locations had a spodic horizon and were polyethylene mulched and subsurface irrigated. Beds were spaced on 6-foot centers with two plant rows per bed. Pepper plants efficiently extracted sufficient K from the low-K soils for adequate crop yields with starter-fertilizer K rates: 40, 25, and 50 lb/acre K_2O at Martin, Palm Beach, and Manatee counties, respectively. Leaf-tissue K concentrations, however, fell below 3.0% (considered inadequate) with the starter rate at Martin and Palm Beach counties and with 100 lb/acre K_2O at Martin County. Warmer spring temperatures induced greater K uptake, resulting in 3.6% midharvest leaf-tissue K concentration in Manatee County with the starter K rate. Yield responses were not different with increasing K rates in any county through 280 lb/acre K_2O. The K rate resulting in the highest RY for all three counties was 100 lb/acre K_2O: 99% RY, 1121 cartons/acre, in Martin County; 100% RY, 847 cartons/acre, in Palm Beach County; and 100% RY, 1370 cartons/acre, in Manatee County (Hochmuth et al., 1987a, 1990, and 1993).

Peppers were transplanted in late September 1987 in Boynton Beach, where conditions were favorable for a fall crop (Shuler et al., 1988a). Soils tested medium in M-1-extracted K (60 ppm), and 100 lb/acre K_2O were recommended. Two side-band applications of starter fertilizer containing half of the recommended K rate, 48-64-48 lb/acre N-P_2O_5-K_2O, resulted in 97% RY. Additional K fertilizer banded at bed center resulted in 100 (1540 cartons/acre) and 97% RY with 110 and 170 lb/acre K_2O, respectively. The significance between yield responses was not indicated.

A reduced K rate of 150 lb/acre K_2O was compared with a higher grower rate of 512 lb/acre K_2O at two Palm Beach County sites. At a third site, the reduced rate was 130 lb/acre K_2O and the grower rate was 306 lb/acre K_2O (Shuler and Hochmuth, 1989). Starter fertilizer was broadcast at all three sites for both experimental and grower rates: 50 lb/acre K_2O were broadcast at the first two sites, and 30 lb/acre K_2O were broadcast at the third site. Beds were spaced 6-feet on center with two plant rows per bed.

Pepper yield response was not different with either 150 or 512 lb/acre K_2O at both trial sites. Soil tests, following application of the starter fertilizer, resulted in medium (43 ppm) M-1-extracted K, and 100 lb/acre K_2O were recommended (Shuler and Hochmuth, 1989). Relative yields with the 150 lb/acre K_2O rate were 91 and 100% (1622 and 1013 cartons/acre) at each location. No yield advantage occurred with the 512 lb/acre K_2O grower rate. Leaf K concentrations were deficient (< 2.5%) at early-harvest sampling at the first location and adequate at the second location. The third Delray Beach site, tested after 30 lb/acre K_2O was broadcast, was low to very low (20 ppm) in soil K and 130 lb/acre K_2O were recommended. Yield response with the higher grower rate of 306 lb/acre K_2O was significantly greater: 100% RY (1200 cartons/acre), compared to 83% RY with 130 lb/acre K_2O. Deficient leaf-tissue K concentrations of < 2.0% at early harvest indicated 130 lb/acre K_2O were not sufficient at this site.

Current IFAS recommendations for subsurface-irrigated mulched pepper specify preplant incorporation of 10 to 20% K with the remainder banded 6 to 10 inches from plants at 2- to 3-inch depths (Hochmuth and Hanlon, 1995). Maximum yields, 100% RY (1339 cartons/acre), occurred in a Delray Beach study when 80 lb/acre K_2O of the fertilizer were broadcast preplant under polyethylene mulch (Hochmuth et al., 1994). Pepper production with banded K fertilizer was most inefficient, leaving large amounts of residual K in the band at the end of the season and resulting in 1117 cartons/acre with the same 80 lb/acre K_2O rate. Higher yields with banded K fertilizer, 1161 cartons/acre, required 240 lb/acre K_2O. Experimental plots were 5.5 x 18 feet.

Unfertilized pepper plants extracted sufficient K from very low, 18 ppm, soils for adequate leaf-tissue K (3.7%) at early fruit set (Hochmuth et al., 1994). Fruit yields, however, were not sustained on unfertilized soil, yielding 561 cartons/acre compared to 1339 cartons/acre with 80 lb/acre K_2O. A fruit-shrivel rating from 1 to 10, beginning with no shrivel to fruit wrinkled and soft, was made for pepper fruits. Shrivel rating generally increased with increasing K rate advancing from ratings of 5.0 to 6.3 to 7.0 for respective K_2O rates of 80, 160, and 240 lb/acre. Higher rates of K_2O fertilization increased shrivel and decreased shelf life of pepper. Excellent yields, 35% above the average state yield for 1993-1994, indicated water management practices were satisfactory.

Extra-large and large fruit yields responded quadratically when all of the broadcast K was supplied from CR-K . At this CR application, extra-large and large fruit yield peaked with a total K_2O application of 160 lb/acre (1362 cartons/acre) and then declined with 240 lb/acre. Total marketable fruit yields with these same rates responded linearly. The slight decline in extra-large and large fruit yield were attributed to excess K with the 240 lb/acre rate. When a portion of K was supplied from a CR source in quantities of 0, 50, or 100% of the broadcast-K, fruit-quality parameters of wall thickness, firmness, shrivel, and fruit dry weight were not affected.

Pepper response to applied K varied, and at times, unexpected amounts were extracted by the crop from soils testing very low in K. Peppers grown in cooler winter-season plantings responded to K near the recommended rates, but peppers grown in warm-season plantings responded to rates near half the recommended rate. No yield response, however, was shown for K rates in excess of the recommended rate. Absorption of K was most efficient with subirrigated pepper when some of the K was incorporated in the soil as opposed to all of the K banded on the bed surface.

Drip Irrigation

Studies of K fertilization of pepper grown with drip irrigation are minimal. Four studies are summarized here, the first is an N and K study conducted at the University of Florida Horticulture Unit (Locascio and Alligood, 1992).

Soluble and CR fertilizers were evaluated from ten N and four K sources. The soluble K source was KNO_3 + NH_4NO_3. Controlled-release K sources were coated KCl + NH_4NO_3, coated KNO_3 + NH_4NO_3, and coated KNO_3 + coated urea. Nitrogen and K from ten sources were applied 40% preplant (87 lb/acre K_2O) and 60% fertigated (130 lb/acre K_2O) once weekly for 10 weeks. Treatments that included KNO_3 received all of the KNO_3 preplant. Single-row beds were spaced 4 feet apart. Pepper plants yielded significantly more with the soluble KNO_3 + NH_4NO_3 source (1175 cartons/acre) than with the coated KCl + NH_4NO_3 (975 cartons/acre). Similar yields resulted with the CR-K sources: coated KNO_3 + coated urea (1068 cartons/acre) and coated KNO_3 + NH_4NO_3 (1010 cartons/acre) compared to both the high and low yields above.

Potassium recommendation for a Live Oak site with medium (56 ppm) M-1 K was 100 lb/acre K_2O (Hochmuth et al., 1992b). Potassium chloride was applied by hand and incorporated at rates of 0, 50, and 100 lb/acre K_2O. Beds were set on 5-foot centers, two rows per bed, and 9-inch between-plant spacing. Early- and total-harvest yields increased linearly with added K. The greatest yield increases for both harvests were between zero and 50 lb/acre K_2O: 67 and 97% early-harvest RY and 86 and 97% (655 cartons/acre) total-harvest RY, with each respective rate. Yield appeared to level off with 50 lb/acre K_2O, increasing only 3% with the recommended 100 lb/acre rate. Whole-leaf K concentrations at early fruit set were adequate with all K_2O rates including zero lb K_2O.

Experiments with N and K fertilization of pepper were conducted in Live Oak (SVREC) on Lakeland fine sand, spring 1992 (Fletcher et al., 1993). Additional data from petiole-sap testing were sought to calibrate N and K concentrations from peppers grown with drip irrigation and polyethylene mulch. Potassium from KCl, with 160 lb/acre NH_4NO_3-N, was broadcast across a 3-foot swath of soil, tilled, and formed into beds for K treatments of 0, 50, 100, 150, and 200 lb/acre K_2O. Very low residual soil K concentrations (18 ppm) were measured with an M-1 soil test, and the IFAS K recommendation, standardized to plants grown on 6-foot bed centers, was 160 lb/acre K_2O. A response to 190 lb/acre K_2O was expected for this experiment where beds were spaced on 5-foot centers. Beds were drip irrigated and soil moisture tensiometer-maintained between -8 and -12 centibars. Cardy ion meters were used to test petiole-sap N and K concentrations.

Yields of marketable and U.S. No. 1 grade fruits increased quadratically (1% probability) with increased K fertilizer. Marketable fruit yields leveled off above 100 lb/acre K_2O (717 cartons/acre, 100% RYcarton weight not specified). Likewise, leaf-tissue K concentrations increased quadratically at all sampling dates, leveling off above 100 lb/acre K_2O (4.8%) at 1st flowering and early fruit set and above 150 lb/acre K_2O (4.9%) during harvest. Plants grown on the very low residual soil K concentrations (0 lb/acre K_2O) had deficient to near-deficient leaf K concentrations at all sample dates. Potassium fertilization had a positive (linear) effect on average fruit weight and on petiole-sap K concentrations at all sampling dates. Petiole-sap concentrations of 3200 ppm through early fruit set and 3900 ppm during harvest were tied with the optimum-yielding K treatment of 100 lb/acre K_2O.

In a Live Oak study, low (20 ppm) M-1-K soils received a recommendation of 130 lb/acre K_2O (Hochmuth and Hochmuth, 1995; Hochmuth and Hanlon, 1995). Soluble KNO_3 and CR polymer-coated KNO_3 were used as the K sources. Fertilizers were blended, applied to the bed, and incorporated at K_2O rates of 100 or 150 lb/acre, with percentages of 0, 25, and 50% supplied from the CR-K source. Beds were set on 5-foot centers with fertilizer-rate calculations based on 6-foot bed centers. Black polyethylene mulch was applied and drip irrigation was tensiometer-controlled at -8 to -12 centibars.

Total marketable yield was similar with 100 or 150 lb/acre K_2O (545 or 554 cartons/acre, respectively). Significantly higher fancy-fruit yield, fewer U.S. No. 2 fruit, and better average fruit weight were reported when 150 lb/acre K_2O were applied compared to the 100 lb/acre rate. Applying the very-low-soil K fertilizer recommendation of 160 lb/acre K_2O on this site, interpreted as either very low or low, improved pepper quality (Hochmuth and Hochmuth, 1995). Data from studies did not show continued improvement in fruit quality and weight with K rates greater than the recommended rate.

Leaf-tissue K concentration at first flowering was 5.6% with 100 lb/acre K_2O and 6.0% with 150 lb/acre K_2Oboth high concentrations for this stage of growth (Hochmuth et al., 1991). Tissue K concentrations remained high through the second harvest period and increased slightly with 25 and 50%

K_2O applied from a CR source. Success with lower fertilizer rates were attributed to careful water management practices and CR fertilizers. Application of the recommended 130 lb/acre K_2O adequately ensured good crop production at this site.

Potassium Summary

Responses of pepper production to K fertilization have been variable (Fig. 2). Yield responses to K fertilization leveled off between 150 and 300 lb/acre K_2O in most studies. However, optimum yields with less-than-recommended rates of K also were reported. In some studies, only small responses to K resulted when large responses were predicted by soil tests. Predictive soil testing for K, a mobile element in sandy soils, appears questionable. The vertical line in Fig. 2 outlines the current maximum K recommendation for peppers grown on soils very low in K. Yield responses in most studies on soils testing very low in K leveled off near 160 lb/acre K_2O. Some responses were still evident in Fig. 2 to about 200 lb/acre K_2O.

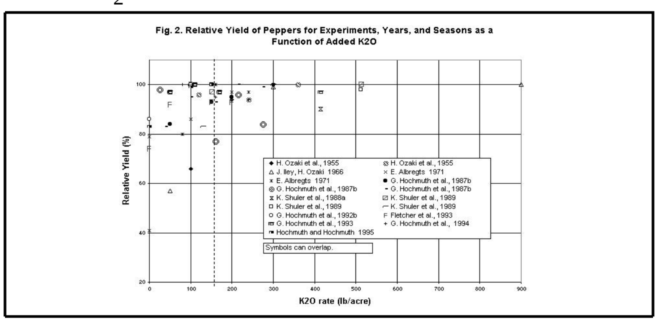

Fig. 2.

Summary

Bell peppers shipped from Florida growers to major cities in the U.S. account for 40% of the marketed peppers in the U.S. While pepper production acreage has remained the same, 21,000 acres from 1981 to 1996, the per-acre yield has more than doubled in that time (Fla. Dept. of Agr. and Cons. Serv., 1997). Annual pepper yields in 1981 resulted in 8 million cartons (412 cartons/acre), while 1996 yields resulted in 19 million cartons (937 cartons/acre). The development of higher-yielding pepper varieties, improvements in plant nutrition and water management practices, and improvements in weed and pest management, likely contributed to recent yield increases.

Continued yield increases require efficient use of water and fertilizers to sustain plant nutritional demands throughout the season while minimizing nutrient losses to the environment. Positive yield results from experiments with CR N-P-K fertilizers encourage further research with single-application, long-term nutrient supply materials. Studies 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 of recommended nutrient management programs on commercial farms are also needed. Some success occurred with CR-K fertilizers used as starter fertilizers on fertigated pepper, but further experimentation is needed to document pepper yield response to fertigated K. Very little research exists for P fertilization of pepper plants. Although P is not mobile within most soils (as with N and K), it accumulates readily with excess application on sandy soils and is readily carried with eroding soils to become a pollutant. Pepper yields responded to less than the recommended P rate in three experiments where soils had very low and medium soil- test P concentrations. No yield response resulted from dry or liquid-injected P sources in two experiments. Additional research is needed to document pepper yield responses to varying P rates and varying methods of P application.

Literature Cited

Albregts, E. E. 1971. Effect of nitrogen and potassium on bell pepper grown under paper mulch. Soil Crop Sci. Soc. Fla. Proc. 31:116-118.

Albregts, E. E., and C. M. Howard. 1973. Effect of fertilization and mulching with biodegradable polyethylene-coated paper on responses of okra and peppers. HortScience 8:36-38.

Csizinszky, A. A. 1997. Response of microirrigated Bell Pepper to phosphorus sources and rates. Soil Crop Sci. Soc. Fla. Proc. 56:20-24.

Everett, P. H. 1977. Controlled-release fertilizers: Effect of rates and placements on plant stand, early growth and fruit yield of peppers. Proc. Fla. State Hort. Soc. 90:390-393.

Everett, P. H., and R. Subramanya. 1983. Pepper production as influenced by plant spacing and nitrogen-potassium rates. Proc. Fla. State Hort. Soc. 96:79-82.

Fletcher J., R. Hochmuth, and G. Hochmuth. 1993. Calibration of N and K fresh-sap quick-test procedures for polyethylene-mulched peppers. Proc. 24th Nat'l Agric. Plastics Congress, Amer. Soc. for Plasticulture.

Florida Agr. Statistics Serv. 1995. Vegetable chemical use. 8 pp. Orlando, FL.

Florida Dept. of Agriculture and Consumer Services. 1998. Florida Agricultural StatisticsVegetable Summary 1996-1997. 70 pp.

Hanlon, E., and G. Hochmuth. 1989. Calculating fertilizer rates for vegetable crops grown in raised-bed cultural systems in Florida. Fla. Coop. Ext. Serv. Spec. Series SS-SOS-901.

Hochmuth, G., D. Maynard, C. Vavrina, and E. Hanlon. 1991. Plant tissue analysis and interpretation for vegetable crops in Florida. Fla. Coop. Ext. Serv. SS-VEC-42. 62 pp.

Hochmuth, G. J., K. D. Shuler, R. Mitchell, and P. Gilreath. 1987a. Nitrogen crop nutrient requirement demonstrations for mulched pepper in Florida. Proc. Fla. State Hort. Soc. 100:205-209.

Hochmuth, G. J., K D. Shuler, P. R. Gilreath, and R. L. Mitchell. 1987b. Field-testing of revised Mehlich-I predicted potassium fertilizer recommendations for mulched pepper. Soil Crop Sci. Soc. Proc. 47:30-35.

Hochmuth, G. J., D. N. Maynard, and M. Sherman. 1988. Pepper production guide for Florida. Fla. Coop. Ext. Serv. Circ. 102E. 18 pp.

Hochmuth, G. J., and E. A. Hanlon. 1989. Commercial vegetable crop nutrient requirements. Fla. Coop. Ext. Serv. Circular 806.

Hochmuth, G. J., and E. Hanlon. 1989b. Fertilizer management for bell pepper production in Florida. Fla. Agr. Expt. Sta. Circular S-357.

Hochmuth, G. J., K. Shuler, and P. Gilreath. 1990. Fertility management for peppers grown with drip and seepage irrigation. Fla. Coop. Ext. Serv. Proc. Fla. Pepper Inst. 1990. SSVEC-002.

Hochmuth, G. J., E. Hanlon, and B. Hochmuth. 1992a. Response of pepper to N fertilization in a polyethylene mulch and drip-irrigation production system at Live Oak, Fl. Spring 1988. Fla. Agr. Expt. Sta. Research Report: Suwannee Valley AREC 92-29.

Hochmuth, G. J., E. Hanlon, and R. Hochmuth. 1992b. Response of pepper, muskmelon, watermelon, and sweet corn to P and K fertilization at Live Oak, FL. Fla. Agr. Expt. Sta. Research Report: Suwannee Valley AREC 92-28.

Hochmuth, G. J., E. Hanlon, B. Hochmuth, G. Kidder, and D. Hensel. 1993. Field fertility research with P and K for vegetablesinterpretations and recommendations. Soil Crop Soc. Fla. Proc. 52:95-101.

Hochmuth, G. J., K. Shuler, E. Hanlon, and N. Roe. 1994. Pepper Response to fertilization with soluble and controlled-release potassium fertilizers. Proc. Fla. State Hort. Soc. 107:132-139.

Hochmuth, G. J., and B. Hochmuth. 1995. Effects of K rate and proportion of K supplied from controlled-release K on pepper. Fla. Agr. Expt. Sta. Research Report: Suwannee Valley REC 95-8.

Hochmuth, G. J., and E. Hanlon. 1995. IFAS standardized fertilization recommendations for vegetable crops. Fla. Coop. Ext. Serv. Circ. 1152.

Hochmuth, G. J. 1996a. Fertilization of pepper in Florida. Fla. Coop. Ext. Serv. Circ. 1168.

Hochmuth, G. J. 1996b. Vegetable fertilization pp. 3-17. IN: G. Hochmuth and D. Maynard (eds.) Vegetable production guide for Florida. Fla. Coop. Ext. Serv. Circ. SP 170.

Hochmuth, G. J. 1997. Response of pepper to Meister controlled-release fertilizers. Fla. Agr. Expt. Sta. Research Report: Suwannee Valley REC 97-02.

Iley, J., and H. Ozaki. 1966. Nitrogen-potash ratio study with plastic-mulched pepper. Proc. Fla. State Hort. Soc. 74:211-216.

Kidder, G., E. A. Hanlon, and G. J. Hochmuth. 1989. IFAS standardized fertilization recommendations for vegetable crops. Fla. Coop. Ext. Serv. Circ. Spec. Ser. SS-SOS-907. July.

Locascio, S. J., and J. G. A. Fiskell. 1977. Pepper production as influenced by mulch, fertilizer placement, and nitrogen rate. Soil Crop Sci. Soc. Fla. Proc. 36:113-117.

Locascio, S. J., and J. G. A. Fiskell. 1979. Pepper response to sulfur-coated urea, mulch and nitrogen rate. Proc. Fla. State Hort. Soc. 92:112-115.

Locascio, S. J., J. G. A. Fiskell, and F. G. Martin. 1981. Responses of bell pepper to nitrogen sources. J. Amer. Soc. Hort. Sci. 106:628-632.

Locascio, S. J., and W. M. Stall. 1982. Plant arrangement for increased bell pepper yield. Proc. Fla. State Hort. Soc. 95:333-335.

Locascio, S. J., and M. Alligood. 1992. Nitrogen and potassium source and N-rate for drip irrigated pepper. Proc. Fla. State Hort. Soc. 105:323-325.

Locascio, S. J., and W. Stall. 1994. Bell pepper yield as influenced by plant spacing and row arrangement. J. Amer. Soc. Hort. Sci. 119 (5):899-902.

Ozaki, H. Y., C. T. Ozaki, and M. G. Hamilton. 1955. The effects of applied nitrogen, phosphorus, and potash on yield and growth of peppers. Proc. Fla. State Hort. Soc. 68:230-233.

Ozaki, H. Y., H. E. Ray, and C. T. Ozaki. 1957. Yields and quality of pepper as influenced by ammonium nitrate and sulfate of potash treatments. Soil Crop Sci. Soc. Fla. Proc. 17:210-215.

Ozaki, H. Y. 1961. Effects of spacing, fertilizer, and variety upon pepper yields. Proc. Fla. State Hort. Soc. 74:178-180.

Ozaki, H. Y., and C. C. Hortenstine. 1962. Effect of applied phosphorus on yield and growth of peppers. Soil Crop Sci. Soc. Fla. Proc. 22:89-92.

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

Shuler, K. D., and G. J. Hochmuth. 1988a. Nitrogen and potassium fertilization of bell peppers, Boynton Beach, FL, fall/winter, 1987-88. Palm Beach. Coop. Ext. Report.

Shuler K. D., and G. J. Hochmuth. 1988b. Nitrogen fertilization of bell peppers, Jupiter, FL. Spring 1988. Palm Beach. Co. Ext. Report. 1988-5.

Shuler, K. D., and G. J. Hochmuth. 1989. Reduced nitrogen and potassium fertilization of bell peppers in Boynton Beach and Delray Beach, FL, fall/winter 1988-1989. Palm Beach. Co. Ext. Report 1989-6.

Singh, K., and V. F. Nettles. 1961. Effect of defloration, defruiting, nitrogen and calcium on the growth and fruiting responses of bell peppers *(Capsicum annum* L). Proc. Fla. State Hort. Soc. 74:204-209.

Smith, S., and T. Taylor. 1996. 1995-1996 Production Cost for selected vegetables in Florida. Fla. Coop. Ext. Serv. Circ. 1176. 65 pp.

Stanley, C., and G. Clark. 1993. Water use and nitrogen balance for subirrigated fresh-market bell pepper, fall '92 crop. Proc. Fla. State Hort. Soc. 106:202-204.