SL343

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

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The purpose of this publication is to summarize squash fertilization research results from studies conducted in Florida. These research results have been used to develop the current University of Florida nitrogen (N) recommendations for squash fertilization. Production of squash in Florida represents almost 3% of the total value of the state's vegetable industry. The value of the squash crop was $52,788,000 in the 2007-08 season (Fla. Agri. Stat. Bulletin 2009). Planted squash acreage has decreased steadily from 9500 acres planted in 1996 to 8600 acres in 2008. Major squash production areas are in southeastern Florida, where 60% of the squash is grown, followed by 16% in the southwest, with lesser production areas in the east, west, and central regions of the state. Peak harvest and out-of-state shipping months occur in December and May, though harvest of squash continues from October to June each year. Various types of squash are grown in Florida, including acorn, butternut, yellow straight and crookneck, white (scallop), and zucchini squash. Florida-grown squash represents 21% of the squash shipped to cities throughout the U.S.

Data Summary Method

Fertilizer is a major part of the crop production expenses for vining and bush squash but is critical for successful crop yields and high fruit quality in Florida. Fertilizer rates are expressed on a per-acre basis (amount of fertilizer used on a crop growing in an area of 43,560 square feet). Changes in bed spacing often lead to needed changes in recommended fertilizer amounts used per acre. 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 recommended 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 was explained by Hanlon and Hochmuth (1989), Hochmuth (1996), and was recently updated by Hochmuth and Hanlon (2009). Fertilizer-rate expressions used in this literature

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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 spacing 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.

In this publication, we attempt to specify planting patterns and fertilizer rates for each experiment as far as could be determined from each report. Current standardized fertilizer recommendations for squash are based on a 6-foot-row (bed) spacing with 2 rows per bed for summer squash or a single row for vining squash. All published squash research results are from studies with mixed N-P-K fertilizers or are N studies.

This document does not present new fertilization recommendations but rather updates the previously published research review, including new research conducted in the last decade. Current squash fertilization recommendations are based on published field research and a compilation of this literature contained in this document will assist with making valid fertilizer recommendations that are both commercially viable and that reduce risk of environmental consequences in adjacent water bodies. As farmers address environmental regulations pertaining to nutrient management it becomes important that fertilization recommendations be based on published research.

This publication documents the previous written literature, some of which now appears only in updated electronic format. All publications, including the reviewed older paper-format publications, will be placed in PDF on the website http://bmp.ifas.ufl.edu for future reference.

Fertilizer recommendations not only contain the recommended fertilizer rate but also the management strategies for getting the most out of the fertilizer investment while protecting the environment. These principles for fertilization of vegetables are summarized by Hochmuth and Hanlon (2010a). Rate is only a part of the modern fertilizer recommendation. Sound fertilizer recommendations also consider fertilizer materials, irrigation, placement, and timing of application, among other aspects (Hochmuth and Hanlon 2010b).

More than 40 years worth of squash fertilization research has been conducted in Florida. During this time, many changes have occurred in squash production practices including changes in cultivars and the introduction of new cultural systems, including polyethylene mulch and drip irrigation. The research reported here covers squash production with polyethylene mulch. Squash crop and fertilizer management recommendations, such as plant and row spacing, have changed with time, keeping with new developments in research (Hochmuth and Maynard 1996; Montelaro 1978; Hochmuth 1988; 1996a; 1996b; Hochmuth and Hanlon 1989; 1995a; 1995b; 2000; Hochmuth and Smajstrla 1997; Kidder et al. 1989; Mylavarapu 2009; Olson et al. 2010; Olson and Santos 2010; Simonne and Hochmuth 2010). Fertilizer is a significant cost input for the grower. The most current recommendations for nutrient management in squash production are presented in the *Commercial Vegetable Production Handbook* for Florida (Olson and Santos 2010). IFAS recommends a target of 150 lb/acre N, and 120 lb per acre P_2O_5, and 120 lb per acre K_2O only when soil concentrations of phosphorus (P) or potassium (K) are very low, based on results of Mehlich-1 (M-1) soil testing (Hochmuth and Hanlon 1995a; 2000). More N can be applied to replace leached N or for extended harvesting seasons (Simonne and Hochmuth 2010).

These recommendations have been in effect for the last decade, after being revised from 108-144-144 in 1974 (Montelaro 1978) to 150-120-120 N-P_2O_5-K_2O in 1989 and 150-120-120 in 1997 (Hochmuth and Hanlon 1989; 1995b; Hochmuth and Cordasco 1999). Despite the recommendations, commercial growers often elect to apply higher rates to reduce the risk of yield reductions given unfavorable production conditions.

The early research focused largely on yield and fruit quality (size and shape) in response to fertilization. Since the early research was conducted and the first literature review in 1999, there have been increasingly strong interests in the incorporation of more environmental impacts (water quality) into the fertilizer research. The state (Fla. Dept. of Agr. and Cons. Serv. 2005; Simonne and Hochmuth 2010) has been formalizing best management practices (BMPs) and encouraging growers to implement BMPs. The definition of a BMP includes consideration of both economics and environmental components and that a BMP embody the best available science.

This literature review includes all available published documentation concerning squash yield and fertilizer use in Florida since the 1960s. We chose to present all the research without being selective to avoid introducing bias to this research summary. Inclusion of all Florida literature shows the development of the commercial production system with respect to fertilizer use. Commercial yields have been increasing primarily due to the proper selection of new cultivars with traits that resist disease and pest pressures and more intensive production practices such as plastic mulched beds. Since the basic plant has not changed, nutrient requirements have also been slow to change. In fact, nutrient use efficiency (due to improved farming practices) has increased while commercial fertilizer rates have not.

The fertilization recommendation addresses commercial yield and quality, the economics of crop production, and protection of the environment. Equally important is to have a mechanism available to the grower to adjust fertilization practices during the season because of leaching rains and extension of the growing season for additional harvests when market conditions are favorable. To address all of these concerns, UF/IFAS vegetable recommendations are given as a single target fertilizer rate that is projected to be sufficient for meeting the crop fertilizer needs for most growing seasons. This single target fertilizer rate is a recommended starting point and has been used historically in all vegetable fertilizer recommendations in Florida, as well as around the country. The target recommendation approach with footnotes was used by Montelaro (1978) and confirmed by Hochmuth and Hanlon (1995; 2000). The target value was derived from numerous fertilizer studies and represents a reasonable fertilizer rate that reflects the average maximum crop responses from all of the fertilizer research, not the extremes in responses. However, the recommendation process recognizes some growing seasons are different due to more leaching rains or increases in crop value that can lead to prolonged harvest windows. Hence, the target fertilizer amount is accompanied by a series of footnotes that explain the addition of supplemental fertilizer during the growing season, which includes addressing leaching rains and additional harvests near the end of the season. It is logical to select a single target rate based on research that avoids excessive fertilizer applications that often reduce crop nutrient efficiency and increase the potential for environmental degradation.

This publication is an updated version of a previous research literature review with the same title by Hochmuth and Cordasco (1999, reviewed 2009), covering fertilizer research through 1996. The audience for this publication includes educators, such as Extension specialists and agents, and commercial vegetable producers, consultants, and governmental agencies.

Data Summary Method

Evaluation of squash yield responses to varying rates of applied fertilizer required a standardized method of summarizing statewide yields, which were expressed variably as kg/ha, Mg/ha, tons per acre, 42-lb boxes per acre, or cwt/acre. In addition, vegetable yields vary depending on season, cultivar, and location in the state. Relative yield (RY), a calculated percentage, was chosen as the unit to express squash yield responses to fertilization. Relative yield is an accepted scientific method for summarizing and presenting data across wide sources and reports (Brown 1987).

In his book, C. Black (1992) summarizes the advantages and disadvantages of the RY approach. There are valid statistical concerns about RY, but he concludes the RY approach can be useful in displaying general relationships when applied properly and cautiously. Black demonstrates examples in his book where RY yield was helpful and where it was not. We chose the RY approach because we wanted to display the historical data without making biased decisions about what to include in the presentation. Plotting absolute yield data in original units obviously would result in a scatter of data rendering any general interpretation impossible. Black (1992) points out that decisions can always be improved with further research, but the data on hand are the best we have at the time. 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 corresponding to 100% RY was presented in the number of 42-lb boxes per acre. The RYs were plotted against rates of nutrient to determine how squash 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. For most studies, RYs of 90 to 100% were not significantly different.

Sometimes the argument is made that growers have expectations of greater yields than those obtained in research projects. Realistic, regularly obtainable yields are often not comparable to expected yields or "yield goals." Research on this subject has documented that 20% of growers actually reached their yield goals; and only 50% reached 80% of their yield goals (Schepers et al. 1986). Therefore, growers rarely achieve their stated yield goals, which means fertilizer rates should not be set on yield goals but rather on realistic goals based on research. This practice of using yield goals to set fertilizer rates has not been recommended in Florida, so the effect of over-fertilization has been avoided by grounding expectations in measurement of observed yields. In effect, the current Florida fertilizer recommendation includes a component that addresses the concern expressed by growers of yield expectation versus actual production capability. Scientists throughout the years have conducted many replicated demonstration studies in growers' fields, with true commercial production practices, and those studies are included in this review. Excessive fertilizer was justified in the past when fertilizer was viewed as inexpensive insurance against yield loss. Research with numerous crops has shown that nutrient use efficiency declines as nutrient rate, especially N, increases. Even given the best of production systems, N-use efficiency rarely exceeds 70% of the applied N. Concepts and practices for managing nutrients in vegetable production were summarized by Hochmuth (1992a, b; 2000). Further, it has been suggested that the yields in older studies were much lower than yields obtained today. However, there are older research reports in the last two decades where yields were as high as yields achieved today.

The highest yield for each fertilizer experiment was designated as 100%, and other yields were expressed as a percentage of the highest yield. The typical yield expression for squash of number of 42-lb cartons per acre was used with all data presented for the actual treatment corresponding to 100% RY. The RY presentation allowed data from many experiments to be included in the summary of yield responses to fertilization. While fertilizer rate is reported in pounds per acre (lb/acre), the reader should keep in mind that the bed system used in each field may vary and require adjustments to the fertilizer rate. To address this issue, the linear bed foot concept (discussed above) can be used to convert among the various bed designs with and without spray rows or ditches (Hanlon and Hochmuth 1989; Hochmuth and Hanlon 2009). Additional cultural practices for commercial squash production can be found in Chapter 2 of the *Vegetable Production Guide* (Simonne and Hochmuth 2010).

Keeping nutrients in the soil profile and available for squash plant uptake requires proper irrigation management. Irrigation information is regularly updated because of the critical nature of irrigation and drainage management with respect to nutrient uptake by the plant and possible loss of nutrients to the environment (Simonne et al. 2010).

Another tool for measuring nutrients, which contributes to appropriate management of fertilizer, includes plant tissue and/or plant sap sampling. For interpretation of plant and petiole sap values, see Hochmuth (1994 a, b) and Hochmuth et al. (1991b; 2009).

Nitrogen

Mixed Fertilizer Trials

Many of the earlier experiments with fertilization of squash were conducted with mixed N-P-K fertilizers. Yield responses from these experiments are presented in Fig. 1, along with yield responses with experiments where N effects were isolated (Dwiekat and Kostewicz 1989; Hochmuth and Hochmuth 1992; Santos et al. 2006; Sutton 1965; and Zotarelli et al. 2008).

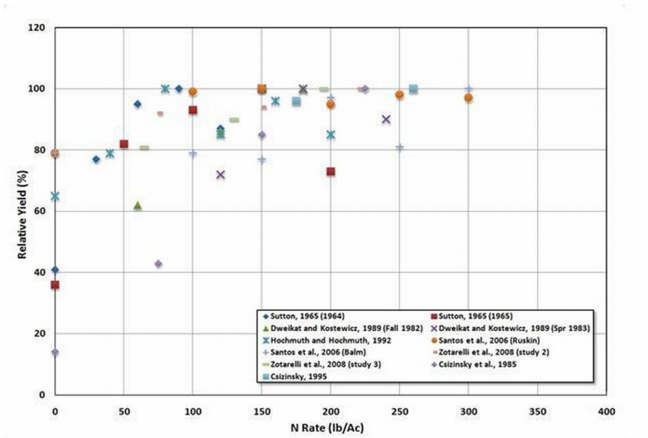

Figure 1. Squash yield responses to rates of N from mixed N-P-K trials and from N trials.

Experimentation with reduced rates of fertilizer was conducted in north Florida, largely to economize on production costs where the vegetable growing season was similar to other areas of the country, and increased competition resulted in lower profits (Robertson and Young 1964). Increased rates of 6-8-6 (N-P_2O_5-K_2O) were applied to Norfolk loamy fine sand soils, described as poorly drained, in a spring 1961 experiment in Quincy (Robertson and Young 1964). Experimental plots, four rows 4 feet apart, were irrigated with an unspecified irrigation system. Prefertilization application of 15 tons of fresh manure (undescribed type) per acre, 1 ton of dolomite per acre, 20 lb/acre N from 15-0-15 (N-P_2O_5-K_2O) and 50 lb/acre N from NH_4NO_3 were made to increase the soil organic-matter content, raise the pH, and increase soil fertility. As the manure source was not documented in this experiment, the total applied N could not be calculated, and yield data could not be presented in Fig. 1. Additional N was applied preplant from 6-8-6 (N-P_2O_5-K_2O) for N treatments of 0, 35, 65, 100, 130, and 165 lb/acre. Marketable yield of 'Early Prolific' squash increased quadratically (5% probability) through the first N increment, 35 lb/acre N resulting in 193 bushels/acre (100% RY). Yield with the highest N rate, 165 lb/acre, was equivalent to the yield with 0 lb/acre, 61% RY. Nitrogen present in the manure was responsible for the limited response to applied fertilizer N.

'Early Yellow Summer Crookneck' squash was grown in the spring seasons of 1964 and 1965 in Dover, Florida (Sutton 1965). Experiments were conducted on Scranton fine sand soils that had not been cropped recently. Squash plants, established in hills 12 inches apart, were thinned to one plant/hill. Rows were 4 feet apart. Five N rates (0, 50, 100, 150, or 200 lb/acre from NH_4NO_3) and five rates of phosphorus (P) and potassium (K) were applied in two equal bands on March 23 and April 13. Beds received overhead irrigation (mulch use was not indicated). Marketable yields increased quadratically for optimum yields with 100 lb/acre N, 93% RY, and 150 lb/acre, 100% RY (159 bushels/acre, bushel weight was not specified). Researchers noted that squash grown with higher N rates had a rougher surface (poorer quality) than those grown with lower N rates.

The combined effects of mulch and fertilizer on yield were the focus of experiments in Quincy, Florida with several vegetable crops at a time when mulches were becoming more widely used (Bryan 1966). Experiments in the spring of 1965 were conducted on Ruston loamy fine sand soils at the North Florida Experiment Station, Quincy. Plots, 50 x 6 feet, were fertilized with 120-80-140 lb/acre N-P_2O_5-K_2O or 240-160-280 lb/acre N-P_2O_5-K_2O. Fertilizers were banded 8 inches to each side of bed center with a basic and sidedress application for unmulched plants and a single preplant application for mulched plants. Double rows of 'Early Prolific' straight-neck summer squash were direct-seeded through black, aluminum-painted black, or clear polyethylene mulch. In a separate experiment, a single row of butternut squash transplants were planted through the same mulch treatments or into unmulched beds. Fertilizers, applied as before, included 180-120-210 lb/acre N-P_2O_5-K_2O or 270-180-315 lb/acre N-P_2O_5-K_2O.

Yields of mulched and unmulched plants were averaged, and optimum 100% RYs occurred with 240 lb/acre N with the straight-neck squash (362 bushels/acre) and with 180 lb/acre for the butternut squash (255 bushels/acre). Nitrogen applied at 270 lb/acre reduced yield of butternut squash to 56% of the yield with 180 lb/acre N. Straight-neck squash plants grown with black or aluminum mulches produced 30% more squash than the unmulched plants, while yields of butternut squash were similar with or without mulch. In 1964, 'Bush Table Queen' acorn squash plants were grown in double rows to compare yield responses of mulched plants (clear, black, or white/black polyethylene mulches) with yield responses of unmulched plants. Unmulched plants received preplant and sidedress fertilizer applications, while mulched plants were fertilized at preplant only. Both treatments were fertilized with 220-180-315 N-P_2O_5-K_2O. Plants mulched with white/black polyethylene had nearly double the early yield (242 bushels/acre) and 1.5 times the total marketable yield (560 bushels/acre) of unmulched plants.

Zucchini squash plants were grown as a second crop following a fall-grown, mulched tomato crop at the Gulf Coast Research and Education Center in Bradenton (Csizinszky et al. 1985). The squash plants were placed on EauGallie fine sand beds, irrigated by subsurface irrigation, and spaced on 4.5-foot centers with fertilizer rates calculated on the standard 6-foot bed spacing for squash. Fertilizer was applied factorially at three rates: 75, 150, or 225 lb/acre N (7,500 linear bed feet of crop per acre); and three application schedules: 100% preplant, 50/50 preplant/mid-growth, or 33/33/33 preplant/mid-growth/prior to harvest. Fertilizer from a 6-1.1-5 liquid N-P_2O_5-K_2O solution was applied as a basic application of 75-13-62 lb/acre (N-P_2O_5-K_2O) and increased 2 and 3 times for the three fertilizer rates. A liquid-fertilizer injection wheel was used to apply the fertilizer through the polyethylene mulch. Zucchini transplants were spaced 24 inches apart in a single row on the bed. Marketable fruit yields increased linearly through 225 lb/acre N (100% RY, 834 bushels/acre) compared to 85% RY with 150 lb/acre N and 14% RY with 0 N. Zucchini yields were significantly greater (1% probability) when the fertilizer was applied twice (50% preplant and 50% at mid-growth, resulting in 785 bushels/acre), compared to yields of plants fertilized once. Plants fertilized in a single preplant application produced 335 bushels/acre, and plants fertilized in three equal applications produced 782 bushels/acre.

Yields were evaluated for squash grown as a succession crop in experiments at Gainesville on fine sand soil and at Quincy on loamy fine sand soil (Clough et al. 1990). 'Dixie Yellow' squash was direct-seeded in the spring (1994) through holes in the polyethylene, where broccoli had grown the previous fall. Combined N and K_2O rates were increased respectively from 120-220 lb/acre to 240-435 lb/acre, including an unfertilized treatment and a uniform application of 230 lb/acre P_2O_5. Nitrogen, P, and K sources, NH_4NO_3, concentrated superphosphate, and KCl, were applied preplant through holes spaced 1 foot apart (overhead irrigation) or applied 40% preplant (N and K), with the remainder injected in weekly increments with the irrigation water for 10 weeks. Overhead irrigation and drip irrigation were applied to meet pan evaporation with adjustments made for rainfall. Residual soil soluble salt concentrations, determined by water extraction, were lower where broccoli was grown with drip irrigation, and researchers cited the significantly higher broccoli harvests and greater leaching potential with drip irrigation compared to overhead irrigation.

Treatment effects interacted for squash yields with a significantly higher yield (5% probability) where overhead-irrigated plants were fertilized with 240 lb/acre N, 955 bushels/acre compared to 809 bushels/acre for plants fertilized with 120 lb/acre N. Increased N did not affect yields of drip-irrigated plants in Gainesville nor drip- or overhead-irrigated plants in Quincy. Very low yields resulted from unfertilized plants in both the overhead- and drip-irrigated plots. Drip irrigation in Gainesville on the sandy soils provided more N efficiency and likewise the heavier soils at Quincy provided more N efficiency.

In the previous publication, leaf- and fruit-tissue mineral concentrations were compared for plants grown with drip irrigation or overhead irrigation (Clough et al. 1990; 1992). Squash leaf-tissue N concentrations, sampled six weeks after emergence, and fruit-tissue N concentrations, sampled at first and final harvest, were similar and within sufficient ranges with N rates of 120 or 240 lb/acre. Less-than-adequate leaf-tissue N concentrations occurred where fertilizer was not applied. Nitrogen accumulation, from whole-plant analysis at harvest, was 63 to 105 lb/acre with N rates of 120 and 240 lb/acre, respectively. Irrigation method did not affect plant tissue N concentrations.

A seaweed foliar spray was applied at three rates to 'Senator' zucchini in an experiment at the Gulf Coast Research and Education Center, Bradenton in spring 1993 (Csizinszky 1995). Plants in the main plots received no seaweed spray, four 28-fluid-ounce applications in April and May, or seven 24-fluid-ounce applications in April through June 8. Subplots received N and K_2O rates of 175 and 240 lb/acre or 260 and 360 lb/acre derived from a 15-0-25 N-P_2O_5-K_2O fertilizer. Nitrogen and K fertilizers were applied in a 2-inch-deep furrow at bed center. All plots received 105 lb/acre P_2O_5 from superphosphate. Beds spaced 5 feet apart were mulched with polyethylene, and zucchini were seeded in double-rows through holes punched in the mulch.

Plants treated with seaweed sprays alone yielded similarly to those treated with water, averaging 656 bushels/acre. An interaction between seaweed spray and applied fertilizer resulted in an optimum 734 bushels/acre when plants received seven seaweed spray applications and 260 lb/acre N. Plants fertilized with 175 and 260 lb/acre N (and no foliar seaweed spray) produced yields of 641 and 670 bushels/acre, respectively. These yields were plotted in Fig. 1. Yields above the state average of 276 bushels/acre (Fla. Agric. Statistics 1993) were likely due to a long harvest period, the cultivar, and production system. Analysis of the dry-matter content of fruits indicated similar macro- and micronutrient concentrations with all fertilizer treatments.

Nitrogen-only Experiments

In spring 1961, an experiment was conducted in Quincy, Florida on Norfolk loamy fine sand soil described as poorly drained (Robertson and Young 1964). Experimental plots, four rows 4 feet apart, were irrigated with an unspecified irrigation system. Prefertilization application of 15 tons of fresh manure (unspecified type) per acre and 1 ton of dolomite per acre were made to increase the soil organic-matter content and raise the pH to 6.5. Increased rates of NH_4NO_3-N were side-dressed in the spring of 1961 at rates of 0, 30, 60, 90, 120, and 150 lb/acre with an additional 125 lb/acre P_2O_5 and K_2O. 'Early Prolific' squash yields this season were similar with all rates of side-dressed N including 0 N treatment, where an 85% RY reflected the prefertilization manure application. Slightly higher yields occurred with 150 lb/acre N, resulting in 707 bushels/acre (100% RY). Yields from this experiment could not be presented in Fig. 2 since the N content of the manure was uncertain.

In an experiment with 'Senator' zucchini squash, within-row plant spacings interacted with N rate in their effects on marketable yield in the fall 1982 experiment season (Dweikat and Kostewicz 1989). Yield results from the spring 1983 experiment are presented here. Both experiments were conducted on Mulat fine sand soils in Gainesville. Nitrogen was applied 60% preplant and 40% at 4 weeks from planting for total N rates of 120, 180, or 240 lb/acre NH_4NO_3. Phosphorus and K, derived from concentrated superphosphate and K_2SO_4, were applied at 180 lb/acre P_2O_5 and K_2O. Fertilizers were applied 8 inches to either side of bed center on beds spaced 4 feet apart. Hills in single or double rows were planted 2 seeds/hill, with hills in the double-row method staggered to 1, 1.5, 2, or 2.5 feet between hills (1 foot between rows). All hills were thinned to one plant per hill. Beds received overhead irrigation, and mulch use was not specified.

Eleven harvests occurred with the spring planting, resulting in a quadratic yield response to N, averaged using all plant spacings. Peak yield occurred with plants fertilized with 180 lb/acre N, 529 bushels/acre (100% RY). Relative yield was reduced to 90% with 240 lb/acre N. Optimum plant density with this experiment occurred with plants in double rows (1 foot between rows) in hills staggered 1.5 feet apart. Yield increases this season compared to the previous fall were attributed to the longer harvest (11 compared to 7 harvests) and application of 180 lb/acre N split 60% preplant and 40% side-dressed at 4 weeks, compared to all fertilizers applied preplant in the fall.

Yields of 'Lemondrop' summer squash were evaluated for response to N rates of 0, 40, 80, 120, 160, and 200 lb/acre NH_4NO_3 in a spring 1990 experiment conducted at the Suwannee Valley

Research and Education Center near Live Oak (Hochmuth and Hochmuth 1992). Nitrogen fertilizers, plus 100 lb/acre K_2O from $K_2Mg(SO_4)_2$, were broadcast in a 36-inch swath and tilled into beds prepared on 5-foot centers. No phosphorus was applied because of high soil concentrations of this nutrient. Beds were mulched with black polyethylene, seeded two rows per bed (15 inches between rows), and drip irrigated to maintain soil moisture at -10 to -12 centibars (monitored by tensiometers). Plants were spaced 1.5 feet apart within each row. Marketable yields in a ten-harvest season responded quadratically (1% probability) to increased N, with peak yield from plants fertilized with 80 lb/acre N (847 bushels/acre, 100% RY). Peak early yield (significant at 5% probability) also occurred with 80 lb/acre N (333 bushels/acre). Upper and lower limits of N fertilization were calculated at 100 to 120 lb/acre based on maximum yield with 76 lb/acre N using the linear-plateau model and 126 lb/acre using the quadratic model. Researchers cited 100 lb/acre N as sufficient for optimum squash yield based on the results of this experiment. Concentration of N in leaf tissue peaked with 120 lb/acre N at 4.4%.

Yields of 'Waltham Butternut' squash, seeded in the fall of 1990 on Lakeland fine sand soils at the Suwannee Valley Research and Education Center near Live Oak, also responded quadratically to increased N (Hochmuth and Hochmuth 1995). Nitrogen rates of 0, 50, 100, 150, 200, or 250 lb/acre from NH_4NO_3 were broadcast in a 30-inch swath with 50 lb/acre P_2O_5 (concentrated superphosphate) and 150 lb/acre K_2O (KCl).

Fertilizers were tilled into beds spaced 7.5 feet apart, mulched with white polyethylene, and planted in a single row with 18 inches between plants. Drip irrigation was applied to maintain soil moisture at -8 to -12 centibars (monitored by tensiometers). Peak yield resulted from plants fertilized with 50 lb/acre N: 285 bushels/acre (100% RY). Yields were reduced at rates of 150 lb/acre N or higher to 55% RY, where plants received 250 lb/acre N. Using the quadratic equation, 97 lb/acre N was calculated as the maximum-yield N rate.

A study to determine the effects of N rates on summer squash was conducted between fall 2005 and spring 2006 (Santos et al. 2006). Three field trials were conducted at the University of Florida Gulf Coast Research and Education Center (GCREC) in Bradenton, Florida (fall 2005 and spring 2006), and at a grower's field near Ruskin, Florida (fall 2005). The soil in both locations was Myakka fine sand, and soil pH and the organic matter (OM) contents ranged between 6.1 to 6.5 and 1.5% to 2.5%, respectively. Owing to the presence of residual soil N, the estimated N release of the Ruskin soils was 25 lb N/acre, while the other two GCREC sites were 45 and 75 lb N/acre for fall 2005 and spring 2006, respectively. Fertilizer application rates were 50, 100, 150, 200, 250, and 300 lb N/acre. Treatments were organized in a randomized complete-block design with six replicates at Ruskin and four and six replicates at Balm. For the trials at Ruskin, an exponential yield response was observed when N rates were increased. While plant vigor increased linearly with a 30% increase from the 50 to 300 lb N/acre N range, the total yield response showed a sharp exponential increase between the 50 and 100 lb N/acre rates, and it remained unchanged at approximately 12.3 ton/acre for all other N rate increases. In GCREC a linear relationship was also observed between increased N rates and plant vigor. However, plant vigor did not have any effect on total yield. The authors suggested that between 50 and 100 lb N/acre could be sufficient to maximize summer squash production depending on the amounts of residual N in the soil from previous growing seasons.

Potassium and Phosphorus

Only a few studies have been conducted throughout the years with P and K fertilization of squash. Small responses to P fertilization were obtained in studies conducted by Sutton (1965) (Figure 2). When there was a response, yield leveled off after 100 lb/acre P_2O_5. Yield leveled off after 100 lb/acre of potassium (K_2O) in studies on sandy soils in Dover (Sutton 1965) (Figure 3).

Irrigation and Nutrient Management

Irrigation and nutrient management are tied closely together for keeping nutrients and water in the root zone. Several irrigation systems are used in

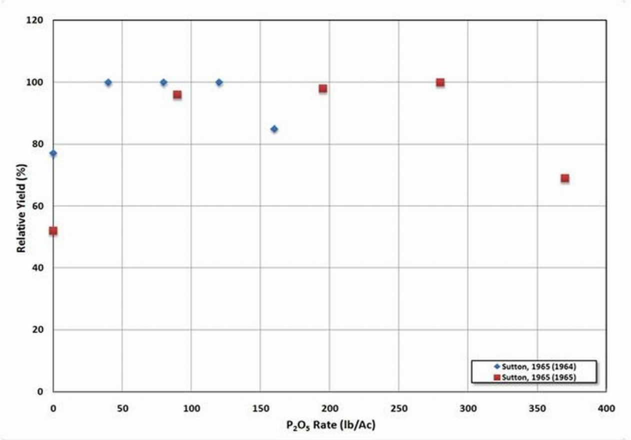

Figure 2. Responses of summer squash to rates of phosphorus fertilizer.

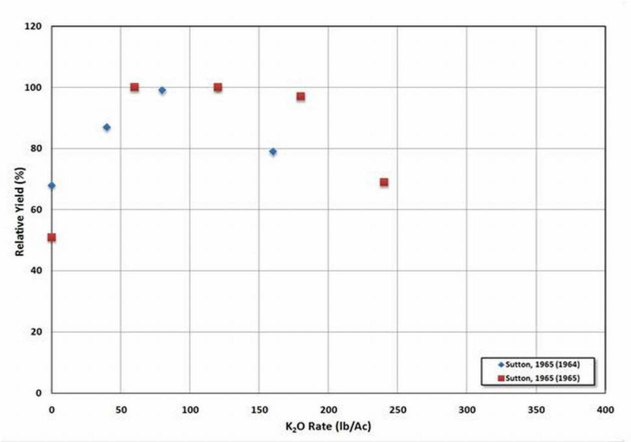

Figure 3. Responses of summer squash to rates of potassium fertilizer.

Florida for irrigating vegetables (Smajstrla and Haman 1998). Irrigation recommendations for squash production are presented by Dukes et al. (2010). Squash production has moved almost entirely to mulched, covered raised beds. With plastic mulch and drip irrigation, growers can inject fertilizers into the irrigation system, improving nutrient management efficiency (Hartz and Hochmuth 1996; Hochmuth and Hartz 1996).

In a study on a sandy soil near Gainesville, Florida, Couto et al. (1999) evaluated N and drip irrigation management in combination for 'Seneca Supreme' yellow squash. N was applied at the standardized linear bed foot rate of 120 lb per acre for beds spaced on 6-foot centers. Two rows of plants were placed on each bed. N fertilizer was applied by fertigation either daily or weekly. Water was applied daily at 80%, 100% (considered optimum), and 125% multiplied by the evapotranspiration rate. There was no interaction between the N and water factors. Squash yield was 18% greater with daily compared to weekly N application. Irrigation level had no effect on fruit yield; using 80% ET was sufficient to supply the plant's water needs with polyethylene-mulched, drip-irrigated squash.

Overall Summary

Only a few studies have been conducted with squash fertilization where effects of N were isolated. The current recommendation is for 150 lb/acre N for squash planted in twin rows on beds on 6-foot centers. This same rate would equal 225 lb/acre N for squash on beds spaced 4 ft apart. These rates were confirmed by most of the research conducted with squash where the effects of N were isolated from effects of other nutrients. It is important to apply N frequently to sustain the rapid early growth of the squash plant. Few research reports were found for P and K fertilization of squash. More research is needed for fertilizer management with squash, especially studies on the relationship of fertilization and water management with nutrient leaching.

Literature Cited

Black, C. A. 1992. Soil fertility evaluation and control. Lewis Publishers, Boca Raton, FL. 746 pp.

Brown, J. R. 1987. Soil testing: sampling, correlation, calibration, and interpretation. Soil Science Society of Amer. Special Publ. No. 21. Soil Science Society of America, Inc. Madison, Wisc.

Bryan, H. H. 1966. Effect of plastic mulch on the yield of several vegetable crops in north Florida. Proc. Fla. State Hort. Soc. 79:139-146.

Clough, G. H., S. J. Locascio, and S. M. Olson. 1990. Yield of successively cropped polyethylene-mulched vegetables as affected by irrigation method and fertilization management. J. Amer. Soc. Hort. Sci. 115:884-887.

Clough, G. H., S. J. Locascio, and S. M. Olson. 1992. Mineral concentration of yellow squash responds to irrigation method and fertilization management. J. Amer. Soc. Hort. Sci. 117:725-729.

Couto, L., D. Z. Haman, G. J. Hochmuth, and A. G. Smajstrla. 1999. Nitrogen and irrigation management for squash production in north Florida. Proc. Fla. State. Hort. Soc. 112:329-332.

Csizinszky, A. A., D. N. Maynard, G. J. Hochmuth, P. R. Gilreath, and R. L. Mitchell. 1985. Liquid fertilization of squash and muskmelon grown as a second crop following tomatoes. Proc. Fla. State Hort. Soc. 98:287-291.

Csizinszky, A. A. 1995. Yield response of 'Senator' zucchini to seaweed spray, micronutrient and potassium rates. Fla. Agr. Expt. Sta. Research Report, Bradenton GCREC BRA-1995-10.

Dukes, M. D., L. Zotarelli, and K. T. Morgan. 2010. Use of irrigation technologies for vegetable crops in Florida. HortTechnology 20:133-142.

Dweikat, I. M., and S. R. Kostewicz. 1989. Row arrangement, plant spacing, and nitrogen rate effects on zucchini squash yield. HortScience 24:86-88.

Florida Agricultural Statistics, Vegetable Summary 1992-1993. Fla. Agric. Statistics Service, Orlando, FL.

Florida Agriculture Statistical Bulletin. 2009. Season vegetables highlights, http://www.nass.usda.gov/Statistics_by_State/Florida/Publications/Annual_Statistical_Bulletin/fasb09p.htm [Accessed April 2010].

Florida Dept. of Agriculture and Consumer Services. 1998. Florida Agricultural Statistics-Vegetable Summary 1996-1997. 70 pp. Fla. Agric. Stat. Serv., Orlando, FL.

Florida Dept. of Agriculture and Consumer Services. 2005. Water quality/quantity best management practices for Florida vegetable and agronomic crops. http://www.floridaagwaterpolicy.com/PDF/Bmps/Bmp_VeggieAgroCrops2005.pdf.

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.

Hartz, T K., and G. J. Hochmuth. 1996. Fertility management of drip-irrigated vegetables. HortTechnology 6:168-172.

Hochmuth, G. J. 1988. Commercial Vegetable Fertilization guide. Fla. Coop. Ext. Serv. CIR 225C.

Hochmuth, G. J. 1992a. Fertilizer management for drip-irrigated vegetables in Florida. HortTechnology 2:27-32.

Hochmuth, G. 1992b. Concepts and practices for improving nitrogen management for vegetables. HortTechnology. 2 (1):121-125.

Hochmuth, G. J. 1994a. Plant petiole sap-testing guide for vegetable crops. Fla. Coop. Ext. Serv. Circ. 1144.

Hochmuth, G. J. 1994b. Sufficiency ranges for nitrate-nitrogen and potassium for vegetable petiole sap quick tests. HortTechnology 4:218-222.

Hochmuth, G. 1996a. 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. 1996b. Commercial Vegetable Fertilization guide. Fla. Coop. Ext. Serv. CIR 225D.

Hochmuth, G. J. 2000. Management of nutrients in vegetable production systems in Florida. Soil and Crop Sci. Soc. Fla. Proc. 59:11-13.

Hochmuth, G. J., and K. Cordasco. 1999 (reviewed 2009) Summary of N Research with squash in Florida. Fla. Coop. Ext. Serv. Cir 750. http://edis.ifas.ufl.edu/pdffiles/CV/CV22700.pdf.

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

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

Hochmuth, G. J., and E. A. Hanlon. 1995b. Commercial vegetable crop nutrient requirements in Florida. Fla. Coop. Ext. Serv. SP 177.

Hochmuth, G. J. 1996. 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., and E. A. Hanlon. 2000. IFAS standardized fertilization recommendations for vegetable crops. Fla. Coop. Ext. Serv. Circ. 1152.

Hochmuth, G. J., and E. A. Hanlon. 2009. Calculating recommended fertilizer rates for vegetable crops grown in raised-bed mulched cultural systems. Fla. Coop. Extension Serv. Circ. SL 303. http://edis.ifas.ufl.edu/pdffiles/SS/SS51600.pdf.

Hochmuth, G. J., and E. A. Hanlon. 2010a. Commercial vegetable fertilization principles. Fla. Coop. Extension Serv. Cir. SL 319. http://edis.ifas.ufl.edu/pdffiles/CV/CV00900.pdf.

Hochmuth, G. J., and E. A. Hanlon. 2010b. Principles of sound fertilizer recommendations. Fla. Coop. Extension Serv. Cir. SL 315.

Hochmuth, G. J., and T. K. Hartz. 1996. Fertility management of drip-irrigated vegetables. HortTechnology 6:168-172.

Hochmuth, G. J., and R. C. Hochmuth. 1992. Nitrogen fertilization of summer squash on a sandy soil. Fla. Agr. Expt. Sta. Research Report, Suwannee Valley REC 92-19.

Hochmuth, G. J, and R. C. Hochmuth. 1995. Butternut squash responses to nitrogen fertilization in polyethylene mulch culture. Fla. Agr. Exp. Sta. Research Report, Suwannee Valley REC 95-4.

Hochmuth, G. J., and D. N. Maynard. 1996. Vegetable production guide for Florida. Fla. Coop. Ext. Serv. Circ. SP 170.

Hochmuth, G. J., D. Maynard, C. Vavrina, E. A. Hanlon, and E. Simonne. 2009. Plant Tissue Analysis and Interpretation for Vegetable Crops in Florida. 55 pg. http://edis.ifas.ufl.edu/ep081.

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

Hochmuth, G. J., and A. G. Smajstrla. 1997. Fertilizer application and management for micro (drip)-irrigated vegetables in Florida. Fla. Coop. Ext. Serv. Circ. 1181.

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

Montelaro, J. 1978. Commercial Vegetable Fertilization Guide. Fla. Coop. Ext. Serv. Circ. 225-B.

Mylavarapu, R. S. 2009. UF/IFAS Extension Soil Testing Laboratory (ESTL) Analytical Procedures and Training Manual Circular 1248, 19 pg. http://edis.ifas.ufl.edu/ss312.

Olson, S.M, and B. Santos. 2010. Vegetable production handbook of Florida. Univ. of Fla. IFAS Extension. http://www.citrusandvegetable.com/Media/2010_VPG/2010_VPG_.pdf [Accessed May 14 2010].

Olson, S. M., E.H. Simonne, W.M. Stall, P.D. Roberts, S.E. Webb, S.A. Smith. 2010. Cucurbit Production in Florida. Fla. Coop. Ext. Serv. Cir. HS 725.

http://edis.ifas.ufl.edu/pdffiles/CV/CV12300.pdf.

Robertson, W. K., and H. W. Young. 1964. Response of vegetables grown in the Quincy area on Norfolk loamy fine sand to fertilizer and soil amendments. Proc. Fla. State Hort. Soc. 77:198-204.

Santos B. M., C. Esmel, and J.P. Gilreath. 2006. Effects of nitrogen rates on summer squash. Proc. Fla. State Hort. Soc. 119:224-225.

Schepers, J. S., K. D. Frank, and C. Bourg. 1986. Effect of yield goal and residual nitrogen considerations on nitrogen fertilizer recommendations for irrigated maize in Nebraska. J. Fertilizer Issues 3:133-139.

Simonne, E., M. Dukes, and L. Zotarelli. 2010. Principles and practices for irrigation management for vegetables. Fla. Coop. Ext. Serv. AE 260. http://edis.ifas.ufl.edu/pdffiles/CV/CV10700.pdf.

Simonne, E. H., and G. J. Hochmuth. 2010. Chapter 2. Soil and Fertilizer Management for Vegetable Production in Florida. Vegetable Production Handbook. HS711. 3-15. http://edis.ifas.ufl.edu/cv101.

Smajstrla, A. G., and D. Haman. 1998. Irrigated acreage in Florida: A summary through 1998. Fla. Coop. Ext Serv. Cir 1220. http://edis.ifas.ufl.edu/ae150.

Sutton, P. 1965. Effect of nitrogen, phosphorus and potassium on squash yield. Soil Crop Sci. Soc. Fla. Proc. 25:46-50.