## Vegetable BMP Research - 2005-2006 Season: Introduction

With more than 20,000 acres planted each year in Collier and Hendry counties, Southwestern Florida is an important production area in the USA for winter fresh-market tomato. Depending on market conditions, production value ranges between $150 and $300 million annually. Growing seasons are defined as fall with planting dates from Aug. to 15 Oct., winter from 15 Oct. to 15 Dec. and spring from 15 Dec. to 1 Feb. These seasons differ in rainfall patterns, temperatures and day length. For example, fall may bring hurricanes, leaching rains, and wide-ranging temperatures; winter brings cool temperatures and unpredictable freezes accompanying cold fronts; spring is typically dry with temperatures cool at the start and warm or hot at the end. Typical growing season lengths are 18, 20, and 16 weeks for fall winter and spring, respectively. These seasons also differ from a marketing standpoint. Prices are highest in Nov –Dec when fall plantings are harvested and tend to decrease thereafter.

South Florida tomato cultural practices attempt to maximize economic return by maximizing productivity. The current UF-IFAS state-wide N fertilizer rate recommendation for tomato is based on a 6-ft bed spacing, and consists of base (200 lbs/acre) and supplemental rates (Olson et al., 2005). For drip-irrigated crops, 40% of the N and K should be applied pre-plant and the remaining injected through the drip system (Dangler and Locascio, 1990; Locascio et al., 1989; Locascio et al., 1997). For seepage irrigation, 40% of N and K should be broadcast incorporated in the bed ("cold mix"), with the rest banded into one or two grooves cut into the bed surface ("hot mix"). For both systems, supplemental fertilizer applications are recommended in addition to the base rate 1) after a leaching rain (3 inches in 3 days or 4 inches in 7 days); 2) when the harvest season is extended (crop in the field for more than 13 weeks); or 3) when leaf or petiole nutrients fall below the sufficiency range under sound irrigation management (Olson et al., 2005). Current UF-IFAS drip irrigation scheduling methods are based on Class A Pan evaporation (Locasio and Smajstrla, 1989; Olson and Rhoads, 1992) or reference evapotransporation (ETo) (Simonne et al., 2005). Both methods aim to maintain soil water tension below 10 kPa (Locascio and Smajstrala, 1996). For seepage irrigation, the water table should be maintained 12 to 16 inches deep during plant establishment, and 24 to 30 inches deep thereafter (Stanley and Clark, 2003). Although drip irrigation produced tomato yields comparable with seep-irrigated production while substantially improving water-use efficiency (Pitts et al., 1988), seepage irrigation is still widely used in southwest Florida for economic reasons (Prevatt et al., 1981).

The "Water Quality/Quantity Best Management Practices for Florida Vegetables and Agronomic Crop" manual was jointly developed in 2001-2004 by the Florida Department of Agriculture and Consumer Services and UF-IFAS (www.floridaagwaterpolicy.com). BMPs are cultural practices that maintain productivity while reducing environmental impact. The BMP manual for vegetables was adopted by rule (5M-6) and by reference in February, 2006. While the BMP manual recognizes several nutrient management strategies (including fertilizer rates that exceed current recommendations), the long-term success of this voluntary program is based on water quality improvement. Although N runoff has not been identified as a widespread problem in south Florida, a concern remains that the combination of excessive fertilization and irrigation may contribute to elevated nutrient concentrations in ground and/or surface waters.

Although it has been documented that UF-IFAS tomato fertilization recommendations are sufficient for maximum yield (Stanley and Clark, 2003), fertilizer rates used to produce southwest Florida tomatoes are typically higher than recommended because growers believe that UF-IFAS rates are too low and do not provide enough flexibility to reflect the different growing conditions found throughout Florida. Because education, demonstration, and direct grower involvement have been keys to increasing BMP adoption in north Florida vegetable fields (Hochmuth et al., 2003; Simonne et al., 2004), a 3-year project was initiated in southwest Florida.

## Vegetable BMP Research - 2005-2006 Season: Objectives

A 3-year project was initiated in southwest Florida in 2004-05 to:

1. establish partnerships with selected tomato growers to evaluate the effects of N fertilization in commercial fields;
2. evaluate the effect of N fertilizer rate on plant growth, nutritional status, yield, disease and pest incidences, and crop market value;
3. determine the optimum N rate for tomato production; and
4. evaluate the cost effectiveness of selected N application rates.

## Vegetable BMP Research - 2005-2006 Season: Field Trial

We conducted eight trials at five commercial farms to evaluated tomato response to N fertilizer rates during the 2005-2006 seasons. Together the cooperating farms represented 16,000 acres (80%) of staked tomato production in southern and eastern Florida. Soils in the area have a sandy surface layer that is prone to leaching (Muchovej et al., 2005). Treatments consisted of N fertilizer rates ranging from 200 to 330 lb/acre N applied to seepage-irrigated tomatoes in a completely randomized experimental design with three replications (Table 1). In drip-irrigated fields, there were two individual zones with 12 sub-plots per treatment. An additional 32 lb/acre for trial 1, 112 lb/acre for trial 2 and 60 lb/acre for trial 3 were applied after the hurricane Wilma passed through the area to compensate the loss of N by leaching. At the seepage-irrigated fields, the UF-IFAS rates were achieved by changing the rate or composition of the hot mix and by applying custom-made blends to keep P, K micronutrients rates constant. The trials represented diverse growing conditions found in Southwest and East Florida, and also included different varieties (mostly ‘Florida 47’ and ‘Sebring’), plant densities (in-row spacing of 18 to 26 inches between plants; 5 or 6 ft bed centers), soil types (described above), and farm sizes (700 to 5,000 acres). Cooperators prepared beds, fumigated the soil, applied bottom and hot mixes and installed polyethylene mulch, transplanted, pruned, staked, irrigated and provided pest and disease control.

Shallow water table monitoring wells were constructed from 4-ft long, 4-inch diameter PVC pipe screened at the bottom 8 inches (Smajstrla, 1997). A float was attached to one end of a 0.75-inch PVC pipe and inserted in to well to serve as the water level indicator. The water table depth was recorded bi-weekly throughout the growing season. At 30 days after transplanting (DAT) and mature plants in two drip-irrigated trial, the shoots of three tomato plants (fruits removed) selected randomly in each treatment were collected and oven dried at 65o C until constant weight to determine dry matter accumulation (Mills and Jones, 1996). Beginning at first flower buds and continuing until third harvest, fresh petiole sap NO3-N and K concentrations were measured bi-weekly using ion-specific meters (Cardi, Spectrum Technologies, Inc., Plainfield, IL) (Olson et al., 2005). In trial 1, the Fusarium crown rot caused by the fungus, Fusarium oxysporum f.sp. radicis-lycopersici first apparent on 12 Jan 05. The number of affected plants per plot increased through 2 Feb 05, the final reading date during season 2004-05 season. At the same location in the 2005-06 season, crown rot symptoms appeared on 10 Jan 06. and the disease progressed until the final reading date of 2 Feb 06. Plants in trial 3 were rated for disease severity of bacterial spot caused by species of the bacteria Xanthomonas, on 2 Jan 06. Six sub-samples were randomly selected within the treatment plots and plants were rated visually by estimating the area of symptomatic leaf tissue.

Harvested plots were 15 to 22 22-ft long row segments of 10 plants. They were clearly marked to prevent unscheduled harvest by commercial crews. Marketable green and color tomatoes were graded in the field according to USDA specifications of number and weight of extra-large (5x6), large (6x6), and medium (6x7) fruit (USDA, 1997). Yield data were subjected to analysis of variance (ANOVA) mean separation using Duncan's Multiple Range Test at the 5% level of significance. Disease severity ratings were examined with ANOVA and treatment means differences were tested for significance by Tukey's multiple comparison procedure.

Southwestern Florida tomato growers harvest mature-green tomatoes in the fall/winter and early spring market windows. Grower prices for fresh tomatoes are set daily and are sensitive to market supplies. Imported tomatoes from Mexico, Europe and Canada compete during the same market windows. In addition, during many seasons, production from other areas in Florida overlaps with the southern Florida tomato harvest.

UF-IFAS research has indicated that Florida tomato growers should be able to achieve maximum economic yield with 200 lb/acre N, but many southwest Florida tomato growers are extremely reluctant to apply this rate. They believe that a 50 % increase to 300 lb/acre N is necessary to support higher yield, thus increasing the likelihood of a favorable economic outcome.

Two economic considerations support grower preference for higher N fertilization rates. First, N fertilizer represents a minimal portion of total tomato production cost. Second, it is in the grower's economic interest to strive for maximum production. Fresh tomato production is a financially intensive enterprise. More than $13,000 is required to plant, grow, harvest, pack, and market one acre of tomatoes. Total fertilization costs (N, P, K, and micronutrients) are estimated to be less than 3% of total costs (Smith and Taylor, 2004). In contrast, fertilizer applied by corn grain farmers in Mississippi represents close to 30% of their total costs production (Mississippi State University, 2005). Given the greater relative importance of fertilizer costs, a Mississippi corn farmer will be much more likely to adjust fertilization rates in the production budget, a Mississippi corn farmer is more likely to adjust fertilizer rates than a Florida tomato grower in response to changes in either commodity or fertilizer prices.

The fresh tomato market is highly volatile. Prices can change on a weekly or even daily basis. The break-even price for a southwest Florida tomato grower is estimated to be more than $9 per 25-lb carton (Smith and Taylor, 2004). Clearly, if market prices are above the break-even point, overall net returns is enhanced with every additional carton that can be harvested and packed. More interestingly, a grower's goal for maximum production is just as strong when prices are below break-even but above the unit cost to harvest, pack, and sell a carton of tomatoes. Within this range of market prices, each additional box of tomatoes lessens the total financial loss for that particular field or block. Hence, under most market conditions, a grower's objective to maximize production corresponds with his or her economic interests. If production with 200 lb/acre N is less than with 300 lb/acre N, a grower is being financially compromised.

The only situations that a lower fertilization rate can be economically justified are when either the market price is below the unit cost to harvest, pack, and sell, or when the value of additional production from an increased N rate does not cover the added fertilization costs. Given fertilizer costs, market prices, harvest, and post-harvest costs, one can compute the threshold production required to economically justify additional N fertilizer. A graph of yield thresholds is generated from the following generic equation:

FERT ($/ac) + [HARV ($/ctn) * YIELD (ctn/ac)] = PRICE ($/ctn) * YIELD (ctn/ac)

Where,
FERT: added cost of additional fertilizer (i.e. nitrogen);
HARV: unit cost to harvest, pack, and market one carton of tomato;
YIELD: additional yield gained from the additional application of fertilizer;
PRICE: market price of a sold carton of tomatoes.

The monetary value for yields from each fertilizer treatment was calculated for each trial. The values compared projected total revenues gained by fertilizer treatment utilizing yield data and market prices reported at the date of each harvest by size category (USDA-AMS, 2005).

## Vegetable BMP Research - 2005-2006 Season: Results

### Weather conditions and supplemental fertilizer applications

Hurricane Wilma crossed over south Florida on October 24, 2005 with 100 miles/h winds and heavy rain. Tomato stems, branches, leaves, flowers, and fruits were blown from plants and entire fields were flooded for more than 8 h. Rainfall recorded by growers during the 2005-2006 season showed accumulations of 18, 6 and 5 inches for fall, winter and spring, respectively (Table 2). Local weather variability within a geographical area can extremely high during the fall particularly as related to the number of leaching rains. Therefore, is important that growers have a working gauge installed to record daily rainfall at each farm location. The IFAS tomato fertilizer recommendation allows supplemental N and K fertilizer applications in specific situations (Maynard et al., 2003), as does the BMP manual (Simonne and Hochmuth, 2003). Under this recommendation, 30 lb/acre of N can be added for each leaching rain event. Therefore, using fall 2005 as an example, a supplemental application of 90 lbs/acre of N fertilizer was permissible due to three leaching rains. However, N fertilizer application rates were 32, 112, and 60 lbs/acre in trials 1, 2 and 3, respectively. No fertilizer addition due to leaching rain was justified during the winter and spring seasons, so N fertilizer application consisted of the base 200 lbs/acre rate only (Olson et al., 2005). These results suggest that analysis and prediction of leaching rain frequency and timing would be valuable for Florida's vegetable growing areas.

Temperatures recorded by the FAWN station in Immokalee for the 2004-2005 growing season showed monthly minimum-maximum temperatures of °F 64-95, 35-91, 30-85, 27-78, 27-81, 23-81, 29-86, and 39-94 for September, 2005 through April 2006, respectively. During that period, temperatures below 38 °F occurred on 23 Dec. (36.4 °F), 28 Dec. (36.8 °F), 7 Jan. (34.0 °F), 8 Jan. (30.6 °F), 16 Jan. (35.0 °F), 9 Feb. (33.0 °F), 10 Feb. (33.5 °F), 13Feb. (34.8 °F), 14 Feb. (27.6 °F), and 19 Feb (32.0 °F). Overall, Southwest Florida was hot and wet throughout the fall, and cool and dry during the winter and spring of 2005-2006.

## Irrigation management

The BMP trial acreage was irrigated 80% by seepage and 20% by drip systems. Seepage irrigation supplies water to the root zone through upward capillary movement (upflux) from an artificially-regulated shallow water table. Since drip irrigation systems supply water to the plant through plastic tubing installed under the plastic mulch, it is possible to more precisely control water and fertilizer applications. The water table in the seepage-irrigated trials fluctuated between about 16 to 20 inches deep (trial 1, trial 2, trial 4, trial 6, trial 7 and trial 8) and tensiometer readings were between 4 and 8 kPa (trial 2, trial 4 and trial 7) Higher soil moisture and water tables were observed during the fall season due to hurricane Wilma. In the drip-irrigated fields, water was applied daily at a volume estimated from the Weather Service Class A Pan evaporation combined with a crop coefficient. The water table depth in drip irrigated trials (trial 3 and trial 5) was lower than in seepage trials, ranging from about 20 to 30 inches. Previous research with seepage irrigation showed that tomato yield was not reduced when water table depth was maintained near 20 inches (Stanley and Clark, 2003). While maintaining a lower water table resulted in reduced water use in that experiment, water table depth fluctuations are likely to occur in large fields because the depth of the restrictive layer supporting the water table may fluctuate in large fields.

## Biomass accumulation

Treatment differences in plant dry weight 30 DAT for all trials and seasons and final dry weight biomass in one trial were not significant different (trial 1, trial 2, trial 4, trial 5, trial 6, trial 7 and trial 8). Only in trial 5, which was drip-irrigated, did the higher N rate produce significantly greater final tomato plant dry weight than the lower rate. Overall, N rates had little effect on tomato biomass regardless of sampling date. This observation contradicts the common concept of judging crop yield potential by the size and color of the plants.

## Plant nutritional status

Petiole sap NO3-N (trial 1, trial 2, trial 3, trial 4, trial 5, trial 6, trial 7 and trial 8) and K (trial 1, trial 2, trial 3, trial 4, trial 5, trial 6, trial 7 and trial 8) concentrations tended to be above the UF-IFAS sufficiency threshold throughout the season at all eight locations and under all N treatments, except for trial 7 where the K was lower than the sufficiency range. Although the higher N rates produced tomato sap NO3-N concentrations that were greater compared with the lower rates, the N nutrition of plants that received either N rate was "sufficient". Sap data suggest that tomato plants were sufficient in N and K regardless of N rate despite experiencing a hurricane, hot and wet weather conditions in the fall, and a cool and dry condition during winter and spring. Hence, monitoring NO3-N sap content as a routine monitoring tool does not seem to be a practical technique and BMP. For drip, irrigation, it may have a value since fertilizer is injected daily, weekly or bi-weekly, but it is not practical for a large farm. For both irrigation methods, petiole sap testing or whole leaf analysis should be used when problems are suspected.

## Disease incidence

The plots with the lowest N rate in trial 1 (200 lb/acre) expressed the highest disease incidence with an average of 53% symptomatic plants in the 2004-2005 season. The other three treatments (236, 260 or 260 lb/acre N plus biosolids) had 10%, 27%, and 20% average disease incidence, respectively. In contrast to the 2004-2005, the plots with the highest rate of N contained the greatest number of affected plants in 2005-2006. The rate that previously had the most incidences, 200 lb/acre N, had the lowest incidence of Fusarium crown rot in the 2005-06 season. On 17 Jan 06, significant differences were detected among treatments for the low rate of N plus compost compared with the high N rate. However, comparison of treatments by the area under the disease progress (AUDPC) did not detect significant differences between treatments. In trial 3, no significant differences were detected between treatments for the severity of bacterial spot, which were 19% and 13% disease severity for the grower and IFAS treatments, respectively. The nutritional status of the plant can have an impact on susceptibility to certain diseases. In general, plants containing higher N concentration are associated with increased susceptibility to diseases caused by Fusarium spp. That association was not observed in the current study. However, differences among treatments were detected for the spring 2005 AUDPC evaluation and for the disease incidence data from 2006, but not the AUDPC values for 2006. Ammonium nitrogen is more favorable to disease at increasing rates than nitrate nitrogen, which became increasing unfavorable with increasing rates of application (Woltz and Jones, 1973). A neutral or slightly higher soil pH is associated with cultural control of Fusarium diseases. The data from these trials do not conform to data reported by Woltz and Jones, but some interaction seems to be occurring at some level. It may be that more critical testing of Fusarium crown rot and the interaction with N and other nutrients would be of value.

## Yield response to N rates

There were no significant yield differences in the first, second, third and total harvests for all size categories during the fall ($P<0.05$) (Trial 1, Trial 2 and Trial 3). Lack of N response was probably due to the extra fertilizer applied after hurricane Wilma, and to the three leaching rains that occurred (Table). Higher N fertilizer rates produced higher yields for large and medium fruits at third harvest during the winter (Trial 4, Trial 5 and Trial 6). Only one trial produced greater extra-large yield with a lower N rate during the winter. In the spring (trial 7 and trial 8), higher N fertilizer rates increased large fruit yield at first and second harvest, but most of the yield differences were found in the third and total harvests for all size categories. Only one trial produced greater total extra-large fruit yields at the lower N rate during spring. These results illustrate that the 200 lb/acre N rate produced lower large and medium yield at third harvest compared with higher rates during a cool and dry growing season. These results show that it may be possible to reduce N rates especially when the risk of rainfall is low (winter and spring), or when only two harvests are expected (late spring). The actual rate needs to be adjusted based on planting date.

## Economical analysis

Figure 5 shows yields that would be required to pay for an additional 100 lb/acre of N fertilizer across a range of market prices from $4.50 to $18.50/box of tomatoes. The additional N is valued at $40/acre to reflect fertilizer costs during the 2005-06 seasons. Figure 5 further assumes that $3.50 is required to harvest, pack, and market each carton of fruit. As market prices increase, the yield threshold decreases dramatically. When market prices are at $4.50/box, an additional 40 cartons of tomatoes/acre would be needed to cover a $40/acre increase in N fertilization cost. When the market price increases to $10.50/box, less than six additional cartons per acre have to be sold before the added fertilizer cost is covered. Figure 5 demonstrates that at current costs for fertilizer, harvesting, packing, and marketing, the yield threshold for an additional 100 lb/acre N fertilizer is low. Given field variability, it is unlikely that differences in yields will be able to detect these small amounts. All points above the yield threshold curve in Figure 5 represent a positive return to the grower from using 100 additional lb/acre N. However, since N fertilizer efficiency decreases as rate increases, the unused N will be left in the field and could potentially cause a water quality problem if it moves off site.

Data from the second year of the southwest Florida Nitrogen BMP study have yet to produce conclusive results as to a presence and/or magnitude of yield differences between N fertilizer rates. In six trials conducted during the fall and winter, only one produced statistically significant yield differences between the 200 lb/acre N recommended rate and a higher grower-standard rate. In fact, in three of the six trials, total yields were numerically greater when using the recommended rate. Of the two trials conducted during spring 2006, one produced significant yield increases at N rates less than 300 lbs /acre. The other showed that higher N rates produced significantly higher yields during the second harvest. For total harvest, however, the lower N rate produced numerically higher yields, but differences were not statistically significant. Conclusive results describing the yield effects of various N fertilization rates should not be expected until several years of data can be pooled together. As the data accumulate, statistical differences may become more apparent or a trend may develop. It is important to recognize that yield variability across seasons will be another economic factor to consider. In any given year, climate and other growing conditions may not combine to produce significant yield differences between lower and higher N fertilization rates. Consequently, the added fertilizer may in fact depress grower returns. But in another year, when more favorable growing conditions exist, the added fertilizer may support significantly higher production. Growers make fertilization decisions in a state of uncertainty with regard to seasonal growing and market conditions. The added economic return during a favorable year may more than offset the costs incurred during the previous years.

What cannot be incorporated into this analysis is the environmental risk of excess N leaving the field. Whether N is an environmental hazard in southwest Florida remains an open question. However, whether it is a problem or not, environmental costs are not part of a grower’s current decision-making process. If N proves to be a real environmental threat, then public policy either through regulation or incentive payments will be needed to force changes in N fertilization rates beyond the direct impact on production. Direct monitoring of nutrient movement in and out of the field may be needed to determine if commercial use of N rates higher than the BMP standard detrimentally affects off-site water quality.

## Grower participation in the project

Growers were highly engaged in the project and we developed strong successful partnerships during the 2005-2006 growing season. Growers provided input in determining fertilizer rates before the season and helped apply the treatments. We noticed that similar rates may be achieved by different combinations of cold and hot mix, and/or different numbers (1 or 2) of hot bands. While for research purposes it was preferable to refer to each situation as a rate, each situation represented a different fertilization program. Project leaders made bi-weekly visits to six trials and weekly visit to two trials throughout the growing season to discuss progress toward the goals and to review in-season bi-weekly and weekly progress reports. These progress reports were farm-by-farm records of sap petiole analyses, water table depth, dry matter accumulation, and yield. Additionally, growers received a final report at the end of the season. Although not a direct part of this project, the connection between irrigation and fertilizer management was discussed. It became clear that limited irrigation scheduling may be done when using a seepage system. The constraint of applying all the fertilizer at the beginning of the season when seepage irrigation is used increases the potential risk of nutrient leaching. However, the risk may be reduced if drip irrigation or mixed systems are used.

Educating farm employees about plant nutrient management was also an important part of the project. For example, employees of several farms were trained in the use of ion-specific electrodes (Cardy meter, Spectrum Technol., Plainfield, Ill.) to monitor sap NO3-N and K concentrations, and to interpret the results. Growers agreed that this tool was a simple, practical way to monitor plant nutritional status.

## Vegetable BMP Research - 2005-2006 Season: Conclusions

In conclusion, results from these second-year trials are encouraging and indicate that this project is on track to achieve its objectives.

1. There were no treatment differences in plant dry weight 30 DAP and final dry biomass in all trials, except in trial 5 where final biomass was higher with higher N rates.

2. Petiole sap NO3-N and K concentrations throughout the season tended to be above the UF-IFAS sufficiency threshold for all N treatments in all trials, but differed depending on irrigation system type.

3. The rate that in previous year had the most incidences, 200 lb/acre N, had the lowest incidence of Fusarium crown rot in the 2005-06 season.

4. During the fall there were no differences in yield due to extra addition of fertilizer application to compensate for the loss of N due to hurricane Wilma. Fertilizer N application greater than 200 lbs/acre produced higher yields of large and medium fruits at third harvest during the winter and

spring season. However, in some situations lower N fertilizer rates increased extra-large fruit yield.

5. The optimum N fertilizer rate for tomato is not a simple “one size fits all”. Recommendations should consider irrigation method (seepage or drip irrigation), growing season (fall, winter and spring) requiring from 15 to 20 weeks from planting to harvest.

6. Tomato yield can fluctuate widely by season and year due to changing weather conditions. Prices are also volatile, which creates an unpredictable economic situation. Nitrogen fertilizer is a minimal production system cost, so growers treat it as inexpensive insurance.

7. A high level of grower engagement created a popular BMP testing program. Cooperating growers indicated willingness to continue testing N rates lower than their standard next year.

8. Fertilizer applied at higher than recommended rates theoretically increased the risk of negative environmental impact. This risk needs to be quantitatively assessed, compared with the economical risk of profit, and possibly reduced through the use of targeted cost-share programs.