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NITROGEN BEST MANAGENMENT PRACTICE WITH TOMATO PRODUCTION IN FLORIDA IN THE 2005-2006 SEASON

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Abstract. **With the development of nutrient best management practices (BMPs) for vegetable crops N fertilizer recommendations must be high enough to ensure maximum economic tomato (*Lycopersicon esculentum* Mill.) yield without detrimentally affecting water quality. The current statewide UF-IFAS N rate recommended rate of 200 lbs/acre (with supplemental fertilizer applications under specified conditions) may need adjustment based on growing season, soil type, and irrigation system type. The objectives of this project were to establish partnerships with southwest Florida tomato growers and to evaluate N fertilizer rate effects on yield. In 2005-2006, eight on-farm trials were conducted in the fall, winter and spring with N rates ranging from 200 to 330 lbs/acre. Total tomato yields did not differ between N treatments except in one seepage/winter trial. Applying more than 200 lbs/acre N produced higher yields of large and medium fruits at third harvest during winter and spring. A high level of grower engagement created a popular BMP program. Tomato yield can fluctuate widely by season and year due to weather conditions. Farm level prices are also volatile, responding to supply fluctuations in Florida and competing production areas. Nitrogen fertilizer is a minimal production system cost, so growers treat it as inexpensive insurance. To change the grower paradigm, BMP N rate research must be conducted during all seasons, at as many locations, and for as many years as possible in order to identify response trends.**

With more than 20,000 acres planted each year in Collier and Hendry counties, Southwestern Florida is an important production area for USA winter fresh-market tomato. Depending on market conditions, production value ranges between about $150 and $300 million annually. Growing seasons are defined as fall with planting dates from August 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 to 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 November-December when fall plantings are harvested and tend to decrease thereafter. 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, production from other areas in Florida may overlap with the southern Florida crop.

The current UF-IFAS state-wide N fertilizer rate recommendation for tomato is based on 6-ft bed spacing, or 7,260 linear feet per acre. The base N fertilization recommendation is a total application of 200 lb/acre with supplemental rates (Olson et al., 2005). For drip-irrigated crops, 40% of the N and K should be applied preplant and the remaining injected through the drip system (Dangler and Locascio, 1990; Locascio et al., 1989, 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 d or 4 inches in 7 d); 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 (Locascio and Smajstrla, 1989) or reference evapotransporation (ETo) (Simonne et al., 2005). Both methods aim to maintain soil water tension below 1.45 psi (Locascio and Smajstrla, 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 comparable tomato yields with seep-irrigated production (Pitts et al., 1988), seepage irrigation is the most widely used method in southwest Florida for economic reasons (Prevatt et al., 1981).

The Florida Department of Agriculture and Consumer Services and UF-IFAS jointly developed the "Water Quality/

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Quantity Best Management Practices for Florida Vegetables and Agronomic Crop" (BMP) manual (www.floridaagwaterpolicy.com). The BMP manual for vegetables was adopted by rule (5M-6) and by reference in Feb. 2006. While under the BMP program there are 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.

UF-IFAS research has indicated that Florida tomato growers should be able to achieve maximum economic yield with 200 lb / acre N, but many southern 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 yields, 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 is more likely to adjust fertilizer rates than a Florida tomato grower in response to changes in either commodity or fertilizer prices.

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 a particular field or block. Hence, under most market conditions, a grower's objective to maximize production corresponds with his or her economic interests. 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.

$$\text{FERT} + [\text{HARV} * \text{AddYIELD}] = \text{PRICE} * \text{AddYIELD}$$

Where,

FERT: added cost of additional fertilizer (i.e., nitrogen) ($ per acre);

HARV: unit cost to harvest, pack, and market one carton of tomato ($ per carton);

AddYIELD: additional yield gained from the additional application of fertilizer (carton per acre);

PRICE: market price of a sold carton of tomatoes ($ per carton).

Fertilizer rates used to produce southwestern 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.

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). Hence a 3-year project was initiated in southwest Florida 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 crop yield; 3) determine the optimum N rate for tomato production; and 4) evaluate the cost effectiveness of selected N application rates. In this paper the results of the 2nd year of this project with a focus on objectives (1) and (2) are discussed.

Materials and Methods

Eight trials were conducted 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 two sup-plots per treatments. In drip-irrigated fields, there were two individual zones with 12 sub-plots per treatment (Table 1). An additional 32 lb / acre N for trial 1, 112 lb / acre N for trial 2 and 60 lb / acre N for trial 3 were applied after the hurricane Wilma passed through the area to compensate the loss of N by leaching rains. 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. Trials 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.

Harvested plots were 15 to 22-ft long row segments of 10 plants. They were marked to prevent unscheduled harvest by commercial crews. Marketable tomatoes were graded in the field according to USDA specifications of number and weight of extra-large (5 × 6), large (6 × 6), and medium (6 × 7) fruit (USDA, 1997). Yield data were subjected to analysis of variance (ANOVA) and mean separation using Duncan's Multiple Range Test at the 5% level of significance.

Results and Discussion

Weather conditions and supplemental fertilizer applications. Hurricane Wilma crossed over south Florida on 24 Oct. 2005 with 100 mph winds and heavy rain. Tomato stems, branches,

Table 1. Experiment number, irrigation type, N rates evaluated, plot size, planting date, and number of harvests in the 2005-2006 N management trials in southwestern and eastern Florida.

Trial number	Farm	Location / County	Season	Irrigation type	N rate ($lb\cdot acre^{-1}$)[z]	Plot number, size (acres)	Planting date	Number of harvest
1	1	Collier	Fall 2005	Seepage	200 to 275, 200 + C[y] Plus 32	3 (0.17)	19 Sept.	3
2	2	Collier	Fall 2005	Seepage	200 and 260 Plus 112	3 (5)	15 Sept.	4
3	5	Collier	Fall 2005	Drip	200 and 260 Plus 60	2 (17)	5 Oct.	3
4	2	Collier	Winter 2006	Seepage	200 and 260	3 (3)	17 Nov.	3
5	5	Collier	Winter 2006	Drip	200 and 300	2 (25)	14 Nov.	3
6	5	Palm Beach	Winter 2006	Seepage	200 and 330	3 (1.5)	18 Nov.	3
7	3	Hendry	Spring 2006	Seepage	200 and 320	3 (0.83)	4 Jan.	3
8	2	Collier	Spring 2006	Seepage	200 and 260	4 (3)	14 Feb.	3

[z]Based on 6-ft spacing.
[y]C = Yard Waste compost 12 tons / acre.

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 be extremely high during the fall particularly as related to the number of leaching rains. Therefore, it 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 lb / acre of N fertilizer was permissible due to three leaching rains. However, N fertilizer application rates were 32, 112, and 60 lb / acre in trials 1, 2 and 3, respectively. No fertilizer addition due to leaching rain was justified during the winter and spring seasons trials (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 (fawn.ifas.ufl.edu) for the 2004-2005 growing season showed monthly minimum-maximum temperatures (°F) of 64-95, 35-91, 30-85, 27-78, 27-81, 23-81, 29-86, and 39-94 for Sept. 2005 through Apr. 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), 13 Feb. (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.

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 ($P < 0.05$) (Table 3). Lack of N response was probably due to the extra fertilizer applied after hurricane Wilma, and to the three leaching rains that occurred during the fall (Table 2). Higher N fertilizer rates produced higher yields for large and medium fruits at third harvest during the winter. Only one trial produced greater extra-large yield with a lower N rate during the winter. In the spring, 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 $lb\cdot acre^{-1}$ N rate produced lower large and

Table 2. Summary of rainfall, number of leaching rain events and possible and applied supplemental N during season 2005-06 tomato seasons.

Trial	Season	Number of days from planting to last harvest	Total rainfall (inches)	Number of leaching rainfalls	Possible[z] and applied supplemental N ($lb\cdot acre^{-1}$)
1	Fall 2005	140	18.2	3	90 / 32
2	Fall 2005	130	18.2	3	90 / 112
3	Fall 2005	133	11.3	1	30 / 60
4	Winter 2006	126	6.2	0	0 / 0
5	Winter 2006	133	6.1	0	0 / 0
6	Winter 2006	133	5.0	1	30 / 0
7	Spring 2006	133	4.5	0	0 / 0
8	Spring 2006	105	4.4	0	0 / 0

[z]UF-IFAS supplemental fertilizer application is allowed after a leaching rain defined as 3 inches in 3 days or 4 inches in 7 days for tomatoes (Olson et al., 2005).

Table 3. Effect of N rates on tomato yield during season 2005-06.

Trial	N rates	Yield (boxes·acre^{-1})[z]												
		First harvest			Second harvest			Third harvest			Total harvest			Total season
		XL[y]	L[y]	M[y]	XL	L	M	XL	L	M	XL	L	M	
								Fall						
1	232	383	319	178	341	275	254	21	103	141	745	697	573	2,015
	232+C[x]	408	360	141	186	287	238	25	48	76	620	695	455	1,770
	275	397	347	178	174	209	180	23	50	91	594	606	449	1,649
	305	316	391	137	97	147	257	6	27	87	418	565	482	1,466
Significance		ns[w]	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
2	308	186	348	213	43	204	179	42	169	268	271	721	660	1,652
	368	176	334	234	16	192	190	46	206	340	238	732	764	1,734
Significance		ns	ns	ns	**[w]	ns	ns	ns	ns	ns	ns	ns	*	ns
3	260	630	166	25	521	273	96	89	104	115	1,239	544	236	2,019
	345	577	168	26	513	306	105	125	115	108	1,216	589	239	2,044
Significance		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
								Winter						
4	200	797	350	87	511	542	273	248	290	195	1,556	1,182	555	3,293
	260	769	328	93	544	544	232	251	372	312	1,564	1,244	637	3,445
Significance		ns	ns	ns	ns	ns	ns	ns	*[w]	*	ns	ns	ns	ns
5	200	495	240	80	283	207	160	68	81	147	846	528	387	1,761
	300	355	220	91	244	221	184	97	110	245	696	551	520	1,767
Significance		**	ns	ns	ns	ns	ns	ns	ns	**	**	ns	**	ns
6	200	347	313	71	114	223	210	94	269	445	555	805	727	2,087
	330	338	292	89	130	229	250	82	296	437	549	816	776	2,141
Significance		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
								Spring						
7	200	1,392	311	38	723	252	163	130	196	169	2,245	759	370	3,374
	320	1,423	408	46	679	328	151	240	312	255	2,341	1,048	452	3,842
Significance		ns	*	ns	ns	*	ns	**	**	**	ns	**	**	**
8	200	871	63	17	505	347	62	41	51	138	1,417	461	217	2,095
	260	659	122	33	347	340	123	31	35	131	1,037	498	286	1,821
Significance		ns	ns	ns	*	ns	*	ns	ns	ns	*	ns	ns	ns

[z]25-lb tomatoes / box.
[y]XL = Extra-large (5 × 6); L = Large (6 × 6); M = Medium (6 × 7).
[x]C = Yard waste compost 12 tons·acre^{-1}.
[w]**,*Significant and ns non-significant at P ? 0.01, P ? 0.05, respectively.

medium yield at third harvest compared with higher rates during a cool and dry growing season. These results also 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. In Fig. 1, 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 per box of tomatoes are shown. The additional N is valued at $40 per acre to reflect fertilizer costs during the 2005-06 season. Costs to harvest, pack, and market are assumed to be $3.50 per carton (Smith and Taylor, 2004). As market prices increase, the yield threshold decreases dramatically. When market prices are low at $4.50 per box, an additional 40 cartons of tomatoes per acre would be needed to cover a $40 per acre increase in N fertilization cost. When the market price increases to $10.50 per box, less than six additional cartons per acre have to be sold before the added fertilizer cost is covered. Figure 1 demonstrates that at current costs for fertilizer, harvesting, packing, and marketing, the yield threshold for an additional 100 lb / acre N fertilizer is low. All points above the yield threshold curve in Fig. 1 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. 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, and that growers make fertilization decisions uncertainty of seasonal growing and market prices at harvest. 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 would depress grower returns. But in another year, when more favorable growing conditions exist, the added fertilizer may

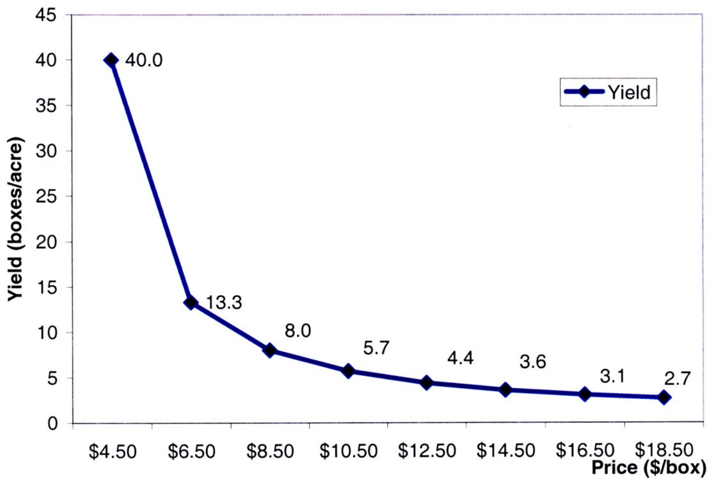

Fig. 1. Yield threshold curve for prices ranging from $4.50 to $18.50 per carton and for increasing N fertilizer from 200 to 300 lb / acre N, assuming nitrogen costs of $.40 per lb and harvesting / packing / selling costs of $3.50 per carton.

support significantly higher production. 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 economic 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 a field may be needed to determine if N rates higher than the BMP standard detrimentally affect down-stream 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. 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.

Growers were highly engaged in the project and successful partnerships were developed throughout the season. 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. 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.

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