Proc. Fla. State Hort. Soc. 127:94–98. 2014.

The Effect of Increasing Rates of Fertilizer on Insect Pests of Organically Grown Squash 'Gentry' (*Cucurbita pepo* L.)

Danielle Treadwell[1]*, Susan Webb[2], Mihai C. Giurcanu[3], and Michael Alligood[4]

[1]*University of Florida, IFAS, Department of Horticultural Sciences, PO Box 110690, Gainesville, FL 32611*

[2]*University of Florida, IFAS, Department of Entomology and Nematology, PO Box 110620, Gainesville, FL 32611*

[3]*University of Florida, Department of Statistics, PO Box 118545, Gainesville, FL 32611*

[4]*University of Florida, IFAS, Suwannee Valley Agricultural Extension Center, 7580 CR 136, Live Oak, FL*

Additional index words. *Bemisia tabaci*, *Aphis gossypii*, aphids, row covers, whiteflies

Organic producers typically apply 100% of their nitrogen (N) requirements as dry granular fertilizer in the bed prior to establishment of plastic mulch and drip irrigation due to the high costs of liquid fertilizer. Insects, particularly those that feed in the phloem, may reach higher levels when there is excess N available. This study examined the effects of three rates of an organic-compliant blended fertilizer on yield and insect pests of yellow crookneck squash, 'Gentry' (*Cucurbita pepo* L.) to determine if increased N rates were associated with greater insect abundance and fruit damage. The design was a complete factorial arranged in an RCBD with three rates of fertilizer N: 84; 168; and 336 kg·ha^{-1} (75, 150, and 300 lb/acre) and three insect management treatments: floating row cover; organic-compliant insecticide as needed for aphids, whiteflies, and caterpillar pests; and no insect control. Squash was planted on 38-centimeter (18-inch) centers on 1.5-meter (5-foot) beds on 25 April on transitional organic land at the Suwannee County Agricultural Extension Center in Live Oak, FL. Each plot was surrounded by a 3-meter (10-foot) border parallel to the rows and a 4.6-meter (15-foot) border perpendicular to the rows. Insect counts were completed in situ weekly prior to squash harvest. The use of row covers at planting resulted in fewer whiteflies and aphids overall compared to remaining treatments, but insect density was not related to fertilizer rate. Marketable yield was greatest in the greatest N application rate, 15,724 kg·ha^{-1} (14,039 lb/acre), relative to the remaining rates of N application ($P < 0.001$) and yields were comparable to state average yields in conventional systems.

Yellow squash is an important vegetable crop in Florida, where it is grown on more than 5900 acres and is primarily sold as a fresh product during the fall and spring (USDA–NASS, 2014). Squash producers can anticipate average yields of 14,112 kg·ha^{-1} (300 bushels/acre) (Olson et al., 2012) and conventional producers typically invest $1.26 per kg or $15,895/ha ($6,433/acre) for production fields on 5-ft spacing, plastic mulch, and drip irrigation (MSU, 2014). Due to the higher costs of production inputs and additional labor hours required for organic management, organic producers invest 30% or more in direct costs (excluding fixed costs, as those would be similar between production systems) to establish and manage the crop, thereby increasing investment to $20,222/ha ($8,184/acre).

The prohibitive cost of liquid fertilizers approved for use in organic production limits fertilizer application strategies. Most Florida organic producers apply 100% of the recommended N as dry granular blended fertilizer, incorporate the fertilizer into the soil, and install plastic mulch and drip irrigation in advance of seeding or transplanting. Plant available N is not always in synchrony with plant N requirements due to the biological processes necessary to mineralize N, posing additional challenges for organic producers (Gaskell and Smith, 2007). To overcome delays in mineralization, organic growers often apply more than the University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS) recommended rate of 168 kg·ha^{-1} (150 lb/acre) of fertilizer N. Higher rates of fertilizer N could exacerbate insect problems, especially those that feed in the phloem.

Higher levels of nitrogen fertilizer have been shown to benefit phloem-feeding insects, such as aphids (Nevo and Coll 2001) and whiteflies (Bentz et al. 1995a, b). In other studies, results have been either inconsistent (Chen and Ruberson 2008), or the highest levels of total amino acids in phloem (resulting from different fertilizer treatments) have had a negative effect on whitefly survival (England et al. 2011). Organic growers want to use levels of fertilizer that are above recommended rates to increase yield, but the effects on pest populations could be detrimental, especially because the insecticides approved for organic production are sometimes not as effective as those used in conventional production.

Consumers demand high quality produce, regardless of the method of production. Quality is even more important for con-

*Corresponding author: phone (352) 273-4775; e-mail: ddtreadw@ufl.edu

sumers who pay a price premium for certified organic produce. Consumers expect organic produce to be free from insect damage and have a similar appearance to conventional produce.

The objectives of this study were: 1) to determine how the UF/IFAS recommended N fertilization rate for yellow squash affects the population density of phloem feeding insects important to yellow squash production; 2) to identify the most effective insect management strategy of those common among organic producers; and 3) to select the combination of insect management strategy and fertilizer N rate that resulted in the lowest insect occurrence, the highest quality fruit, and greatest yield.

Materials and Methods

Experimental design. Nine treatments were arranged in a randomized complete block design and replicated four times for a total of 36 plots. Treatments included three rates of N fertilizer and three insect management treatments. Fertilizer rates were selected because they are above and below the University of Florida's N fertility recommendations for field-grown yellow squash of 168 kg·ha^{-1} (150 lb acre^{-1}) as follows: 84; 168; and 336 kg·ha^{-1} (75, 150, and 300 lb acre^{-1}). The fertilizer (Rhizogen AgLife, Microbes Biosciences, Woodlands, TX) had an analysis of 3% N, 0.873% P and 1.66% K. Insect treatments typical of Florida organic growers included floating row covers (Agribon, Johnny's Selected Seeds, Fairfield, ME) and organic-compliant insecticide as needed for aphids, whiteflies, and caterpillar pests, and these were compared to a third treatment of no insect management. Insecticides used included *Bacillus thuringiensis* subsp. *kurstaki* (Dipel DF, Valent BioSciences, Libertyville, IL), azadirachtin (Neemix 4.5, Certis USA, LLC, Columbia MD), and insecticidal soap (Des-X, Certis USA, LLC, Columbia, MD). Each plot consisted of four 7.6-m (25-ft) long rows on 1.5-m (5-ft) centers.

Crop management. All inputs and practices were consistent with the USDA's National Organic Standards (USDA AMS, 2013). Fertilizer was applied by hand on 19 Apr. 2013 to each plot and was incorporated with a rototiller prior to installation of white on black plastic mulch and drip irrigation [RoDrip 30 cm (12 inch) emitter spacing, John Deere, Moline, IL]. Yellow crookneck squash (*Cucurbita pepo* 'Gentry' L.) was direct-seeded on 46-cm (18-inch) spacing within rows on organically-managed land at the Suwannee Valley Agricultural and Demonstration Center in Live Oak, FL. Irrigation was scheduled to match estimated losses to evapotranspiration, and irrigation frequency and duration increased with crop maturity.

Data collection. Insect counts were conducted *in situ*, weekly, beginning on 17 May with the first squash harvest and ending on 18 June. Adult *Bemisia tabaci* (Gennadius) B strain (whiteflies), all stages of *Aphis gossypii* Glover (melon aphids), adults, nymphs, and eggs of *Anasa tristis* (De Geer) (squash bug), and small (1st and 2nd instar) and large (3rd and 4th instar) *Diaphania hyalinata* (L.) (melonworm) were counted on ten half plants per plot (one side of the plant). On the first sampling date, floating row cover treatments were still in place so no counts were conducted for this treatment on that date. Covers were removed the following week before sampling to allow pollination to occur. On 18 June, the number and type of insect predators and parasitoids were counted on one plant per plot (four per treatment). Also on 18 June, one to two leaves from each of 10 plants at roughly the same height above the planting bed (a total of fifteen leaves from each plot) were collected and transported to the laboratory in Gainesville for examination using a stereomicroscope. Alate and apterous aphids were counted separately on the detached whole leaves, while immature whiteflies were counted on leaf disks cut from the leaves with a cork borer. Immature whitefly counts were recorded as the sum of either eggs, small (first and second instar), or large (third and fourth instar) nymphs on three disks per half leaf, with a total area of 2.54 cm^2 (1 inch^2).

Squash was harvested weekly for six weeks beginning 17 May through 18 June from the center two rows of each plot, excluding border plants at row ends. Fruit was sorted by size using a harvest aid to distinguish USDA market grades of No. 1, No. 2, No. 3, and culls. Fruit in each grade group was counted and weighed per plot. Fruit that was misshapen, damaged by insects, or otherwise imperfect was classified as a cull. The only observed and recorded insect damage was caused by pickleworm [*Diaphania nitidalis* (Stoll)], but damage was minimal and not different among treatments.

Statistical analysis. To assess the effects of fertilizer N rate, insect treatment, and time on the adult whitefly counts, we fit a Poisson Generalized Linear Mixed Model (GLMM) for adult whiteflies versus the main effects of fertilizer, insect treatment, and time, and the interaction effects between fertilizer and insect treatment, with random effects for the blocks. We fitted the Poisson GLMM model using the SAS/GLIMMIX software, Version 9.4 of the SAS system for Windows, 2014, SAS Institute. Similar analyses were conducted for aphids (using a negative binomial distribution), squash bugs, and melonworm larvae, as well as for counts of alate and apterous melon aphids and immature stages of whitefly from detached leaves, using a Poisson or negative binomial distribution, as appropriate. Estimated means were separated using Tukey-Kramer at $\alpha = 0.05$. A multivariate analysis (MANOVA) was used to analyze natural enemy counts. Squash yield (counts and weights) were analyzed with SAS V.9.4 using PROC GLM and means separation with Fischer's Protected LSD at $\alpha = 0.05$.

Results and Discussion

Insects. The whitefly population was generally low (Table 1), but some significant differences were found for adult whiteflies counted directly on plants. The main effects of time (Table 2) were significant with an F-test statistic of $F_{4,1644} = 17.43$ and a *P*-value < 0.001. The main effect of fertilizer was not significant, however, while the main effect of insect treatment and the interaction effects between fertilizer and insect treatment were significant. Table 3 shows the Tukey-Kramer letter grouping of predicted adult whitefly means per half plant for the fertilization by insect treatment groups. This shows that the combination of the intermediate rate of fertilizer combined with the use of row covers resulted in a significantly lower mean number of adult whiteflies per half plant than any other fertilizer by insect treatment combination. Because the interaction effects of fertilizer N rate and insect treatment were significant, further analyses were performed to identify the fertilizer levels for which the insect management effects were significant and the insect management treatments for which the fertilizer effects were significant using the analysis of simple effects for the two-way interactions. For example, Table 4 shows that for the untreated control treatment, the predicted mean number of whiteflies for the low fertilizer rate is significantly lower than the predicted mean for the high fertilizer rate.

Melon aphid populations were somewhat higher than whitefly populations, but still relatively low (Table 5). The main effects of time (Table 6) were significant with an F-test statistic of $F_{4,1644} =$

Table 1. Mean number of adult whiteflies per half plant by treatment and date.

Treatment		Sampling date									
Fertilizer	Insect	17 May		24 May		31 May		7 June		14 June	
N rate[z]	Management	Mean	SE[y]	Mean	SE	Mean	SE	Mean	SE	Mean	SE
84	Untreated	0.18	0.05	0.03	0.01	0.03	0.01	0.14	0.04	0.08	0.02
84	Row cover	0.17	0.06	0.02	0.01	0.03	0.01	0.13	0.04	0.07	0.02
84	Insecticide	0.16	0.04	0.02	0.01	0.03	0.01	0.12	0.03	0.07	0.02
168	Untreated	0.35	0.07	0.05	0.02	0.06	0.02	0.27	0.06	0.15	0.04
168	Row cover	0.04	0.03	0.01	0.00	0.01	0.00	0.03	0.02	0.02	0.01
168	Insecticide	0.38	0.07	0.06	0.02	0.06	0.02	0.30	0.06	0.16	0.04
336	Untreated	0.39	0.08	0.06	0.02	0.06	0.02	0.30	0.06	0.16	0.04
336	Row cover	0.17	0.06	0.02	0.01	0.03	0.01	0.13	0.04	0.07	0.02
336	Insecticide	0.20	0.05	0.03	0.01	0.03	0.01	0.16	0.04	0.08	0.02

[z]The fertilizer N rate ($kg \cdot ha^{-1}$) is equivalent to 75, 150, or 300 lb/acre of N.
[y]SE = standard of error.

Table 2. Type III F tests for the fixed effects for analysis of adult whitefly counts.

Effect	Numerator DF	Denominator DF	F Value	Pr > F
Date	4	1660	17.45	< 0.0001
Fertilizer Rate	2	1660	1.44	0.2381
Insect Management	2	1660	6.01	0.0025
Fertilizer*Insect	4	1660	3.05	0.0161

Table 3. Tukey-Kramer letter grouping of predicted means of adult whiteflies per half plant for the fertilizer nitrogen (N) rate by insect management groups; the effects that are assigned the same letter are not significantly different based on the adjusted *P*-values of the Tukey's test for all pairwise comparisons.

Fertilizer N rate[z]	Insect management	Estimate
168	Insecticide	–1.9414 a
336	Untreated	–1.9554 a
168	Untreated	–2.0237 ab
336	Insecticide	–2.5833 bc
84	Untreated	–2.6886 bc
84	Insecticide	–2.8064 bc
336	Row cover	–3.0114 c
84	Row cover	–3.0114 c
168	Row cover	–4.5518 d

[z]The fertilizer N rate ($kg \cdot ha^{-1}$) is equivalent to 75, 150, or 300 lb/acre of N. Mean separation in column by Tukey-Kramer, 5% level.

Table 4. The F-test for fertilizer nitrogen (N) rate by insect management interaction means slice for untreated control and the Tukey-Kramer predicted Fertilization means of adult whiteflies.

Slice	Num DF	Den DF	F Value	Pr > F
Untreated	2	1660	3.56	0.0288

Slice	Fertilizer N rate[z]	Estimate
Untreated	336	–1.9554 a
Untreated	168	–2.0237 ab
Untreated	84	–2.6886 b

[z]The fertilizer N rate ($kg \cdot ha^{-1}$) is equivalent to 75, 150, or 300 lb/acre of N. Mean separation in column by Tukey-Kramer, 5% level.

15.28 and a *P*-value < 0.001. As with adult whiteflies, the main effect of fertilizer was not significant, while the main effect of insect treatment and the interaction effects between fertilizer and insect treatment were significant. Table 7 shows the Tukey-Kramer letter grouping of the predicted mean number of aphids per half plant for the fertilizer by insect treatment groups. This shows that the combination of the high rate of fertilizer and row covers resulted in a significantly lower mean number of aphids per half plant than any other fertilizer by insect treatment combination. Because the interaction effects of fertilizer and insect treatment were significant, we also identified the fertilizer levels for which the insect treatment effects were significant and the insect treatments for which the effects of fertilizer were significant using the analysis of simple effects for the fertilizer by insect treatment interactions. For example, Table 8 shows that for the row cover treatment the predicted average number of aphids under the high rate of fertilizer was significantly lower than the predicted average number of aphids per half plant under the intermediate rate of fertilizer.

There were so few squash bugs and melonworm larvae that no significant differences were found (data not shown) for time, fertilizer rate, or insect treatment. There were also no detectable differences among treatments for number of lacewing eggs and larvae; lady beetle eggs, larvae, and adults; big-eyed bug, parasitoid wasps, and spiders; or among treatments for immature stages of whiteflies or melon aphids counted on detached leaves (data not shown). In the case of the detached leaf counts, the number of insects found was very low.

In general, insects were not abundant during the course of this experiment. Melon aphids and whitefly populations were highest on the first sampling date and then on the last two dates, with melon aphids the most abundant. There was no effect of fertilizer N rate on the density of melon aphids or whiteflies. The floating row cover treatment always had the fewest aphids and whiteflies, even though plants were uncovered before the second sampling. It is possible that the main aphid flights occurred during the time when row covers were still in place. Because of the low numbers of insects overall, the interactions of fertilizer rate and insect management tactics are somewhat difficult to interpret. For example, the fewest aphids were found in the floating row cover treatment that received the highest rate of fertilizer. For whiteflies, the row cover treatment and the intermediate rate of fertilizer had the fewest insects, while the intermediate rate of

Table 5. Mean number of aphids (all stages) per half plant by treatment.

Treatment		Sampling date									
Fertilizer	Insect	17 May		24 May		31 May		7 June		14 June	
N rate[z]	Management	Mean	SE[y]	Mean	SE	Mean	SE	Mean	SE	Mean	SE
84	Untreated	1.54	0.41	3.64	0.92	1.75	0.46	3.62	0.97	4.20	1.13
84	Row cover	0.50	0.15	1.18	0.34	0.57	0.16	1.17	0.32	1.36	0.37
84	Insecticide	1.22	0.33	2.90	0.76	1.40	0.36	2.88	0.76	3.35	0.89
168	Untreated	1.69	0.45	4.01	1.02	1.93	0.50	3.98	1.06	4.62	1.24
168	Row cover	0.58	0.17	1.38	0.40	0.66	0.19	1.37	0.38	1.59	0.42
168	Insecticide	0.94	0.26	2.24	0.58	1.08	0.28	2.22	0.59	2.58	0.70
336	Untreated	1.55	0.42	3.67	0.94	1.77	0.47	3.66	0.95	4.24	1.13
336	Row cover	0.31	0.09	0.73	0.21	0.35	0.10	0.73	0.21	0.85	0.23
336	Insecticide	1.29	0.35	3.05	0.79	1.47	0.38	3.03	0.79	3.52	0.95

[z]Rate $kg \cdot ha^{-1}$ of N is equivalent to 75, 150, or 300 lb/acre of N.
[y]SE = standard of error.

Table 6. Type III F tests for the fixed effects for aphid counts.

Effect	Numerator DF	Denominator DF	F Value	Pr > F
Time	4	1644	15.28	<.0001
Fertilizer Rate	2	1644	0.84	0.4337
Insect Management	2	1644	41.84	<.0001
Fertilizer*Insect	4	1644	2.49	0.0417

Table 7. Tukey-Kramer letter grouping of least squares means for aphids per half plant for the fertilization by insect treatment groups; the effects that are assigned the same letter are not significantly different based on the adjusted *P*-values of the Tukey's test for all pairwise comparisons.

Fertilizer[z]	Insect treatment	Estimate
168	Untreated	1.0974 a
84	Untreated	1.0002 a
336	Untreated	0.9954 a
336	Insecticide	0.8249 ab
84	Insecticide	0.7738 ab
168	Insecticide	0.5134 bc
168	Row cover	0.1608 cd
84	Row cover	0.01349 d
336	Row cover	–0.4588 e

[z]$kg \cdot ha^{-1}$ N is equivalent to 75, 150, or 300 lb/acre of N.
Mean separation in column by Tukey-Kramer, 5% level.

Table 8. The F-test for Fertilizer x Insect treatment interaction means slice for row covers and the Tukey-Kramer predicted mean aphids by fertilizer rate.

Slice	Num DF	Den DF	F Value	Pr > F
Row covers	2	1644	3.66	0.0260

Slice	Fertilizer[z]	Estimate
Row covers	168	0.1608 a
Row covers	84	0.01349 ab
Row covers	336	–0.4588 b

[z]$kg \cdot ha^{-1}$ N is equivalent to 75, 150, or 300 lb/acre of N.
Mean separation in column by Tukey-Kramer, 5% level.

Table 9. Squash yield influenced by the main effects of fertilizer nitrogen (N) rate (84,168, or 336 $kg \cdot ha^{-1}$ N) ($P < 0.0001$) and insect management strategy (untreated, compliant insecticides, or row covers) ($P < 0.0001$) in an organically managed system.

Treatment	Squash Yield ($kg \cdot ha^{-1}$)	
Fertilizer N rate[z]	Marketable	Total
84	11,026.08	15,247.72
168	12,760.02	21,385.26
336	15,724.02	27,743.04
LSD	1,598	5,364
Insect Management	Marketable	Total
Untreated	6,298.50	10,378.44
Row Cover	7,245.50	11,817.46
Insecticide	6,211.06	9,990.16
LSD	398.66	564.64

[z]Equivalent to 75, 150, or 300 lb/acre of N.

fertilizer with no insect management had the most. When insects were not managed, the plants with the highest fertilizer rate did have more whiteflies than those receiving the lowest rate, the only indication that high fertilizer N rates might lead to higher whitefly populations. No such effect was found for aphids.

When squash marketable yield was examined on a weekly basis, marketable yield was influenced by a fertilizer rate and time (weekly harvests) interaction ($P < 0.0001$) largely due to a decline in harvested yield during week three. There were no other statistical interactions. Squash marketable yield was influenced more by time among the weekly harvests (F = 344.22; $P < 0.0001$) than it was influenced by fertilizer rate (F = 31.86; $P < 0.0001$) or insect management strategy (F = 12.86; $P < 0.0001$). The total marketable yield (sum of all weekly marketable yield) was influenced by the main effects of fertilizer rate ($P < 0.0001$) and insect management strategy ($P = 0.0027$), but there was no fertilizer rate by insect management treatment interaction (Table 9).

In summary, the use of row covers at planting resulted in fewer whiteflies and aphids overall compared to remaining treatments, but insect density was not related to fertilizer rate at the rates of N evaluated and under the low insect pressure at this location, with the possible exception of whiteflies on untreated plants. Marketable yield was greatest in the 336 $kg \cdot ha^{-1}$ N relative to remaining rates ($P < 0.001$).

Literature Cited

Bentz, J., J. Reeves III, P. Barbosa, and B. Francis. 1995a. Nitrogen fertilizer effect on selection, acceptance, and suitability of *Euphorbia pulcherrima* (Euphorbiaceae) as a host plant to *Bemisia tabaci* (Homoptera: Aleyrodidae). Environ. Entomol. 24:40–45.

Bentz, J., J. Reeves III, P. Barbosa, and B. Francis. 1995b. Within-plant variation in nitrogen and sugar content of poinsettia and its effects on the oviposition pattern, survival, and development of *Bemisia argentifolii*. Environ. Entomol. 24:271–277.

Chellemi, D. and G. Lazarovits. 2002. Effect of organic fertilizer applications on growth, yield, and pests of vegetable crops. Proc. Fla. State Hort. Soc. 115:315–321.

Chen, Y. and J.R. Ruberson. 2008. Impact of variable nitrogen fertilisation on arthropods in cotton in Georgia, USA. Agr. Ecosyst. Environ. 126:281–288.

England, K.M., C.S. Sadof, L.A. Cañas, C.H. Kuniyoshi, and R.G. Lopez. 2011. Effects of selected fertilizers on the life history of *Bemisia tabaci* (Hemiptera: Aleyrodidae) biotype B. J. Econ. Entomol. 104:548–554.

Gaskell, M. and R. Smith. 2007. Nitrogen sources for organic vegetable crops. HortTechnology. 17(4):431–441.

Mississippi State University (MSU). 2014. Dep. of Agr. Econ. 2013 Vegetable budgets. Accessed 2 June 2014 . <www.agecon.msstate.edu>.

Nevo, E. and M. Coll. 2011. Effect of nitrogen fertilization on *Aphis gossypii* (Homoptera: Aphididae): Variation in size, color, and reproduction. J. Econ. Entomol. 94:27–32.

Olson, S., P.J. Dittmar, P.D. Roberts, S.E. Webb, and S.A. Smith. 2013. Cucurbit production in Florida. Veg. Prod. Guide. Fla. Fla. Coop. Ext. Serv.

USDA–AMS. 2013. National Organic Program. <www.ams.usda.gov/nop/>.

USDA–NASS. 2014. 2012 Census of agriculture. Florida agricultural statistics. USDA–NASS-Florida. Table 38. Vegetables, potatoes, and melons harvested for sale: 2012 and 2007. <agcensus.usda.gov>.