Manipulating fertilization: a management tactic against *Frankliniella occidentalis* on potted chrysanthemum

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Abstract

Fertilization during production of greenhouse chrysanthemum, *Dendranthema grandiflora* (Tzvelev), will influence *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) populations as well as plant productivity and postproduction longevity. It is essential to include fertilization effects in the development of crop management practices that reduce thrips populations and maintain plant marketability. In this study, we lowered fertilization to reduce thrips population abundance while maintaining plant productivity. We tested fertilization levels below and above the recommended level (375 p.p.m. N) for commercial production. We reduced mean rate of change in *F. occidentalis* abundance from 0.05 to 0.03 (day^{-1}) and mean number of thrips per plant by 44% by fertilizing with either 188 p.p.m. N (50% of the recommended level) or 568 p.p.m. N (150%) and higher. Fertilization influenced not only the rate of change in thrips abundance but also the production time (from transplanting to flower opening). Lowering fertilization to 50% of the recommended level lengthened mean production time from 84 to 88 days. Plant height, flower size, and flower number were not adversely affected when fertilization was reduced to 50% of the recommended level. Mean postproduction longevity was shortened from 26 to 24 days when plants were fertilized with 50% of the recommended level. Two important advantages of lowering fertilization to 50% of the recommended level were (1) a 44% reduction in mean *F. occidentalis* abundance and (2) a significant reduction in fertilizer input for the production system. Manipulation of fertilization can be a useful management tactic against *F. occidentalis*.

Introduction

Chemical fertilizers are used extensively in greenhouse ornamental production to ensure production of high quality crops. These fertilizers provide essential nutrients for plant growth but also inadvertently elevate the nutritional quality and attractiveness of plants to phytophagous insects (van Emden, 1966; Minkenberg & Fredrix, 1989; Bentz & Larew, 1992). Early studies on plant quality and insect growth focused on nitrogen effect and found that higher levels of leaf nitrogen may enhance both growth and reproduction of herbivorous insects (Mattson, 1980; Larsson, 1989; Waring & Cobb, 1992). More recent studies showed that population growth rate and development time of phytophagous insects are influenced not only by plant nutrient levels but also by nutrient ratio (Busch & Phelan, 1999; Jansson & Ekbom, 2002). However, excessive fertilization can be detrimental to not only aphids and thrips (Jansson & Smilowitz, 1986; Bethke et al., 1998; Chau et al., 2004) but also to their host plants (Schuch et al., 1998; Scheirs & De Bruyn, 2004).

van Emden & Wearing (1965) suggested that manipulating fertilization to slow pest development can be used to enhance the effectiveness of biological control agents. When pest development is reduced, it may also minimize insecticide usage. If fertilization can be manipulated to slow pest population growth, this tactic may be used with biological control (Berndt et al., 2004), host plant resistance (Bergh & Le Blanc, 1997; de Kogel et al., 1998; Maris et al., 2004), and other cultural practices (Schuch et al., 1998; Stavisky et al., 2002) for effective control of important pests such as thrips.

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Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), is a severe and worldwide pest of greenhouse crops (Tommasini & Maini, 1995; Lewis, 1997). *Frankliniella occidentalis* vectors diseases and causes feeding damage to over 200 vegetables and ornamentals including greenhouse-grown chrysanthemum, *Dendranthema grandiflora* (Tzvelev) (Robb, 1989; Childers & Achor, 1995). This thrips prefers to feed within flowers and buds, which protects the pest from insecticides and natural enemies. *Frankliniella occidentalis* can also rapidly develop and maintain insecticide resistance (Immaraju et al., 1992; Jensen, 2000; Kiers et al., 2000). It is difficult to control *F. occidentalis* using chemicals or natural enemies alone and high fertilization rates may accentuate the problem.

Several studies have shown that *F. occidentalis* populations respond positively to increased fertilization. On field-grown tomatoes, the abundance of *F. occidentalis* increases with higher rates of fertilization (Brodbeck et al., 2001; Stavisky et al., 2002). On chrysanthemum, *F. occidentalis* populations also increase with greater fertilization. Schuch et al. (1998) found twice as many *F. occidentalis* infesting chrysanthemums fertilized with 240 p.p.m. N compared to plants fertilized with 80 p.p.m. N. Chau et al. (2005) showed that rate of change in *F. occidentalis* abundance increases from 0 to 375 p.p.m. N and was four times higher on plants fertilized with 375 p.p.m. N than on plants with no fertilization and 1.4 times higher compared to plants fertilized with 75 p.p.m. N. A complete fertilizer was used in both studies on chrysanthemum and thrips responses were attributed to increases in the entire suite of macro- and micronutrients rather than nitrogen alone.

We have previously examined the feasibility of manipulating fertilization, both macro- and micronutrients, to reduce thrips populations on chrysanthemum (Chau et al., 2004, 2005). In a growth chamber study, we found that the population growth rate of *F. occidentalis* on chrysanthemum increases with fertilization level from 20 to 100% of the recommended level (375 p.p.m. N) (Chau et al., 2004). However, we also found that the population growth rate of *F. occidentalis* decreases at 150% of the recommended level or higher. From our study, we concluded that *F. occidentalis* population growth rate could be reduced by either lowering fertilization level to 20% of the recommended level or raising it to 150% or higher.

Raising fertilization level would not be a suitable tactic for controlling *F. occidentalis* on chrysanthemum because it would increase fertilizer input and production cost. Lowering fertilization can be a useful management tactic, but only if it can reduce thrips populations without affecting plant productivity. Validation of this tactic requires investigation of the effects of fertilization on thrips populations as well as plant productivity and postproduction longevity under conditions that approximate commercial production. In this study, we used *F. occidentalis* and chrysanthemum, *D. grandiflora* cv. 'Charm', as our experimental system. Our two objectives were (1) to determine the effect of fertilization on population growth of thrips on chrysanthemum under greenhouse conditions and (2) to examine the effect of fertilization on chrysanthemum productivity and postproduction longevity.

Materials and methods

Effect of fertilization level on *Frankliniella occidentalis* populations

We hypothesized that plant nutrition affects rate of change in *F. occidentalis* abundance and predicted that lowering fertilization level below the recommended level would reduce *F. occidentalis* abundance on chrysanthemum under greenhouse conditions. Plant nutrition, both macro- and micronutrients, was manipulated uniformly by treating plants with different levels of a complete fertilizer. The recommended fertilizer rate for constant liquid feeding of potted chrysanthemum ranges from 250 to 400 p.p.m. N (based on nitrogen) (Dole & Wilkins, 2004); therefore, 375 p.p.m. N was used as the recommended level (100%) for our studies. The amount of phosphorous and potassium in 375 p.p.m. N fertilizer solution is 175 and 354 p.p.m., respectively. To examine *F. occidentalis* responses to fertilization below and above the recommended level, we tested six fertilization levels: 75 (20%), 188 (50%), 281 (75%), 375 (100%), 568 (150%), and 750 (200%) p.p.m. N. We used reverse-osmosis-filtered tap water (RO water) to make the fertilizer solutions (Peters Professional Peat-lite special, 15-16-17; Scotts-Sierra Horticultural Products Company, Marysville, OH, USA). To keep the ratio of all macro- and micronutrients the same, we varied only the strength of the fertilizer to the levels specified above.

We produced potted chrysanthemums following the commercial guidelines (Yoder Brothers Inc., 2001) under greenhouse conditions that approximated commercial production in Texas. We used an experimental protocol similar to the greenhouse study described in Chau et al. (2005). A single rooted chrysanthemum cutting was transplanted into each pot (15.5 cm in diameter × 10.5 cm in depth; Dillen Products, Middlefield, OH, USA). Pots were placed on two greenhouse benches. Each pot served as a replicate and we used a randomized design with five replicates per treatment per bench, totaling 10 replicates per treatment. Plants were fertilized with 200 ml of fertilizer solution twice a week right after transplanting. Terminating fertilization prior to flowering increases postproduction longevity of chrysanthemum (Nell & Barrett, 1990; Roude et al., 1991). Thus, we terminated fertilization at bud break and recorded the total number of days from transplanting to bud break for each plant. Tracking the time from transplanting to bud break allowed us to quantify the duration of fertilizer use and calculate production cost. After bud break, we watered the plants with 200 ml of RO water twice a week until harvest.

We inoculated the plants with adult *F. occidentalis* 1 day after application of daminozide, a plant growth regulator (B-Nine WSG, Uniroyal Chemical Company Inc., Middlebury, CT, USA). The plants were approximately 4 weeks old at the time of thrips inoculation. To inoculate an individual plant, we isolated five female adults from our stock colony in a 1.5-ml microcentrifuge tube (USA Scientific Inc., Ocala, FL, USA) and released the thrips from the tube near the base of the plant. We maintained the *F. occidentalis* colony in the laboratory at 26 °C, 65% r.h., and under a L14:D10 h photoperiod on kidney bean, *Phaseolus vulgaris* L., using the protocol of Arthurs & Heinz (2002). Freshly excised chrysanthemum leaves and inflorescences (flower heads) were added to the thrips colonies 2 days prior to experimentation to allow newly emerged adult thrips to feed.

We allowed the thrips to settle and reproduce on the plants for 2 weeks and then counted the number of thrips on each plant at weekly intervals. Flowering times of plants vary with fertilization level (Chau et al., 2005). To standardize harvest time, we harvested each plant when all the terminal buds were fully open and recorded the total number of days from transplanting to flower opening. Time from transplanting to flower opening (production time) is crucial to growers because it influences production cost, crop turnover rate, and, possibly, pesticide usage. Flowers that are heavily damaged by thrips do not open fully. To determine when to harvest our thrips-infested plants, we planted additional pots (10 per fertilization level) and kept these pots free of thrips for the duration of the experiment. These thrips-free plants were inspected daily and any thrips found on these plants were removed immediately. At harvest, we used the same method described in Chau et al. (2005) to extract all thrips from each of the thrips-infested plants. We cut each plant at soil level and immediately placed the whole plant in a sealed plastic container (25 × 25 × 10 cm; Rubbermaid Home Products, Wooster, OH, USA). To dislodge any thrips that were on the plant, we shook the container vigorously. All thrips were removed using an aspirator and stored in 70% alcohol until they were counted.

Thrips counts were first transformed to their natural logarithms (ln-transformed) to satisfy the assumption of homogeneity of variances and then analyzed using one-way repeated-measures ANOVA with fertilization level as the main factor (Hand & Crowder, 1996). The Greenhouse–Geisser probability corrected for sphericity was also calculated (Hand & Crowder, 1996). Differences in thrips numbers may be influenced by both fertilization level and time to harvest. To separate these factors, we also estimated the rate of change in *F. occidentalis* abundance per day by plotting ln-transformed thrips counts against time and calculating the slope of the regression line for each replicate. Rates of change in *F. occidentalis* abundance were then analyzed using one-way ANOVA with fertilization level as the main factor. Time from transplanting to bud break was analyzed using the Kruskal–Wallis test with fertilization level as the main effect. Production time was analyzed using one-way ANOVA with fertilization level as the main effect.

Effect of fertilization level on chrysanthemum

It is generally known that plant productivity and longevity vary with fertilization level. For this second experiment, we assessed how chrysanthemum productivity and longevity were affected by reduction of fertilization. The 60 thrips-free pots (10 pots per fertilization treatment) used to determine harvest times for the first experiment were simultaneously used for this study. These pots were placed on two greenhouse benches and arranged in a randomized design with five replicates per fertilization level per bench, totaling 10 replicates per fertilization level. We randomly assigned half of these plants (five replicates per fertilization level) to be used for plant productivity assessment and the other half for postproduction longevity assessment. For plant productivity assessment, we measured plant height and counted the total number of flower heads produced at harvest. To measure flower head size, we used at least five fully open terminal flower heads per plant and recorded the largest diameter of each open flower. The experiment was conducted from 9 September to 10 December 2004. Temperature and relative humidity inside the greenhouse were 24.7 ± 0.3 °C and 65.0 ± 1.5% r.h. (mean ± SE, n = 92 days). Day length during this period at College Station, TX, USA (30.6°N, 96.3°W) was 11.2 ± 0.1 h.

For postproduction longevity assessment, individual plants were moved from the greenhouse to an office environment. We measured plant height and counted the number of flowers for individual plants and placed the plants on desks. The plant canopy was 1.7 m from the cool-white fluorescent lamps in the ceiling. The average photosynthetically active radiation at the plant canopy was 12.1 μmol s^{-1} m^{-2}. The plants were maintained in the room under a L9:D15 h photoperiod to simulate office conditions. Temperature and r.h. inside the office were 20.0 ± 0.4 °C, 51.5 ± 1.7% r.h. (mean ± SE, n = 37 days). Plants were watered with RO water as needed to keep the potting media moist. Postproduction longevity was the total number of days until the plants were judged to be unattractive. A plant was considered unattractive when the first 2–3 rows of the outer ray flowers lost turgidity, the petal edges started rolling, and the disk flowers in the center of the flower head lost turgidity and turned brown or when the leaves turned yellow or brown, whichever came first.

Plant height and number of flowers were analyzed by two-way ANOVA, with fertilization level and plant assessment as the main factors. Flower size and postproduction longevity were analyzed using the Kruskal–Wallis test. The adjusted Kruskal–Wallis H statistic was calculated when there were ties. Tukey's honestly significant difference test (HSD) was used to determine significant differences between pairs of mean values following parametric tests, and the Games and Howell method (Sokal & Rohlf, 1995) was used following nonparametric tests.

Results

Effect of fertilization level on *Frankliniella occidentalis* populations

Population abundance of Frankliniella occidentalis*.* The total number of weekly counts was different among fertilization levels because of different harvesting times. Therefore, we compared the number of thrips among fertilization levels only for the first six counts. There was a significant fertilization effect on thrips abundance (Figure 1). A significant interaction between fertilization level and time suggested that thrips counts varied differently between fertilization levels (one-way repeated-measures ANOVA: $F_{25,270} = 2.18$; Greenhouse–Geisser adjusted $P = 0.005$). When pooling across sampling dates, the number of thrips was twice that on plants fertilized with 75 or 100% of the recommended level (back-transformed means: 41 and 36, respectively) than on plants fertilized with other fertilization treatments (back-transformed means ranged from 14 to 20).

Rate of change in Frankliniella occidentalis *abundance.* We found a significant fertilization effect on the rate of change in thrips abundance (Figure 2). The mean rate of change in thrips abundance increased from 0.02 to 0.05 (day^{-1}) when fertilization level increased from 20 to 100% of the recommended level. When fertilization level increased beyond 100% of the recommended level, the mean rate of change in thrips abundance reduced to 0.03 (day^{-1}), a 40% reduction in growth.

Effect of fertilization level on chrysanthemum

Duration of fertilization. We found that time from transplanting to bud break was influenced by fertilization level (Table 1). The flower buds on plants fertilized with 20% of the recommended level started to break around 10.2 weeks, whereas the flower buds on plants fertilized with other treatments broke open sooner, around 9.7 weeks. Our results showed that duration of fertilizer use was shortened when plants were fertilized with greater than 20% of the recommended level.

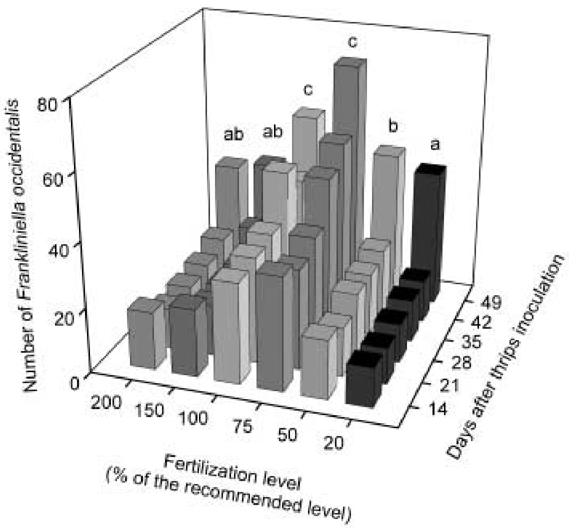

Figure 1 Mean number of *Frankliniella occidentalis* per pot at weekly sampling intervals (days) on chrysanthemums treated with different fertilization levels: 20, 50, 75, 100, 150, or 200% of the recommended level (375 p.p.m. N) (n = 10). Different letter(s) above the bars indicate significant differences between fertilization levels, pooled across sampling dates, at $P \leq 0.05$ as determined by one-way repeated-measures ANOVA, based on ln-transformed means, and followed by Tukey's HSD (one-way repeated-measures ANOVA: $F_{5,54} = 27.73$, $P<0.001$). Untransformed mean values and SEs of the first six weekly counts were presented here.

Production time. Time from transplanting to flower opening (production time) was shortened with increased fertilization (Table 1). Production time was shortest for plants fertilized with 200% of the recommended level (11.8 weeks) and longest for plants fertilized with 20% of the recommended level (13 weeks). Production time was similar for plants fertilized with 75, 100, or 150% of the recommended level (around 12 weeks). Production time was shorter for plants fertilized with 50% of the recommended level (12.6 weeks) compared to those fertilized with 20% of the recommended level but was longer compared to plants receiving other fertilization treatments.

Plant growth and productivity. We found significant fertilization effects on both plant height and number of flowers produced (Table 2). Plants fertilized with 20, 50, 75, or 100% of the recommended level were similar in height but taller than plants fertilized with 200% of the recommended

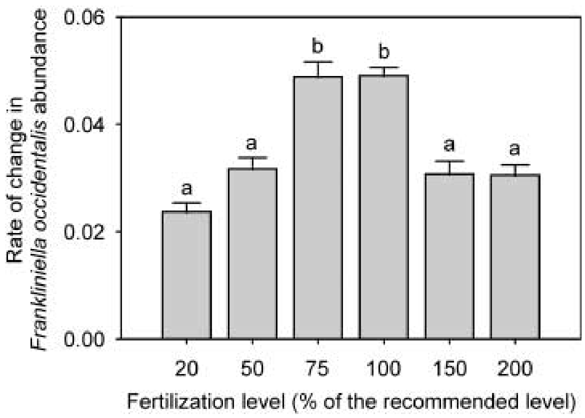

Figure 2 Rate of change in *Frankliniella occidentalis* abundance per plant per day (+ SE) on plants fertilized with 20, 50, 75, 100, 150, or 200% of the recommended level (375 p.p.m. N). Different letter(s) above the bars indicate significant differences among fertilization treatments at $P \leq 0.05$ as determined by one-way ANOVA and followed by Tukey's HSD (one-way ANOVA: $F_{5,54} = 28.28$, $P<0.001$).

level. Number of flowers produced increased with fertilization from 20 to 50% of the recommended level but began to decline when fertilization level exceeded 150% of the recommended level. We also found no significant differences in plant height and number of flowers produced between the plants used for plant growth measurements and those used for postproduction longevity assessment (two-way ANOVA: $F_{1,48} = 0.002$, $P = 0.96$ and $F_{1,48} = 0.08$, $P = 0.79$, plant height and number of flowers produced, respectively). There was no significant interaction between fertilization level and plant assessment (two-way ANOVA: $F_{5,48} = 1.31$, $P = 0.28$ and $F_{5,48} = 1.91$, $P = 0.11$, plant height and number of flowers produced, respectively). Flower size was also influenced by fertilization level (Table 2). Flower size increased with fertilization from 20 to 100% and remained the same beyond 100%.

Postproduction longevity. We found a significant fertilization effect on chrysanthemum postproduction longevity (Table 1). Our results showed that postproduction longevity increased from 13 to 27 days as fertilization was raised from 20 to 75% of the recommended level but did not increase further with fertilization levels beyond 75% of the recommended level.

Discussion

Our results demonstrated that population abundance of *F. occidentalis* could be reduced by either lowering fertilization to 50% of the recommended level, or raising fertilization to 150% or higher. We showed that the mean rate of change in *F. occidentalis* abundance increased from 0.02 to 0.05 (day^{-1}) when fertilization increased from 20 to 100% of the recommended level but did not increase beyond the recommended level (375 p.p.m. N). The rate of change in *F. occidentalis* abundance on plants fertilized with 150% or higher was 0.6 times lower than those on plants fertilized at the recommended level. Thrips responses to fertilization were consistent with earlier studies (Schuch et al., 1998; Chau et al., 2004, 2005), although the magnitude of the responses differed slightly. By lowering

Table 1 Effect of fertilization level on number of days from transplanting to bud break and flowering of thrips-free chrysanthemums and their postproduction longevity (number of days indoor)

Fertilization level	Number of days from transplanting to		Number of days indoor
(% recommended level)[1]	Bud break[2] mean (SE)	Flowering[3] mean (SE)	Longevity[4] mean (SE)
20	71.60 (0.58)a	90.90 (0.43)a	13.40 (1.78)a
50	68.20 (0.42)b	88.40 (0.50)b	23.60 (0.40)b
75	67.60 (0.48)b	85.20 (0.55)c	26.60 (0.75)bc
100	67.10 (0.23)b	84.40 (0.45)c	26.40 (0.40)c
150	67.80 (0.42)b	84.30 (0.50)c	27.00 (0.63)c
200	67.20 (0.20)b	82.30 (0.15)d	26.60 (0.40)c

[1] 375 p.p.m. N was the recommended level (100%) in this study.
[2] Differences between means (n = 10) within column sharing the same letter(s) are not significantly different ($P>0.05$) as determined by Kruskal–Wallis test and followed by the Games and Howell method (Kruskal–Wallis test: $H = 30.23$, d.f. = 5, $P<0.001$).
[3] Differences between means (n = 10) within column sharing the same letter(s) are not significantly different ($P>0.05$) as determined by one-way ANOVA test and followed by Tukey's HSD (one-way ANOVA test: $F_{5,54} = 48.83$, $P<0.001$).
[4] Differences between means (n = 5) within column sharing the same letter(s) are not significantly different ($P>0.05$) as determined by Kruskal–Wallis test and followed by the Games and Howell method (Kruskal–Wallis tests: $H_{adj} = 21.96$, d.f. = 5, $P<0.001$).

Table 2 Effect of fertilization level on plant height, number of flowers produced, and flower size of thrips-free chrysanthemums at harvest

Fertilization level (% recommended level)[1]	Plant height (cm)[2] mean (SE)	No. of flowers[2] mean (SE)	Flower size (cm)[3] mean (SE)
20	25.05 (0.58)ab	32.30 (2.20)a	6.75 (0.08)a
50	27.26 (0.47)a	42.10 (0.88)b	7.25 (0.06)b
75	26.47 (0.58)ab	41.90 (1.89)bc	7.31 (0.18)abc
100	26.48 (0.75)ab	43.00 (2.10)b	7.58 (0.04)c
150	24.18 (0.43)bc	36.40 (1.25)ac	7.38 (0.14)bc
200	22.61 (0.63)c	33.00 (1.39)a	7.37 (0.23)abc

[1]375 p.p.m. N was the recommended level (100%) in this study.
[2]Differences between means (n = 10) within column sharing the same letter(s) are not significantly different ($P>0.05$) as determined by two-way ANOVA and followed by Tukey's HSD (two-way ANOVA: $F_{5,48} = 9.04$, $P<0.001$ and $F_{5,48} = 8.76$, $P<0.001$, plant height and number of flowers produced, respectively).
[3]Differences between means (n = 5) within column sharing the same letter(s) are not significantly different ($P>0.05$) as determined by Kruskal–Wallis test and followed by the Games and Howell method (Kruskal–Wallis test: $H_{adj} = 11.65$, d.f. = 5, $P = 0.04$).

fertilization to 50% of the recommended level, we reduced mean *F. occidentalis* abundance by 44% which could substantially reduce thrips feeding damage on plants.

Our study conditions were representative of a production greenhouse with *F. occidentalis* moving freely within the crop and between benches. *Frankliniella occidentalis* adults are relatively weak fliers and have a limited dispersal capability with the average rate of spread between consecutive generations fluctuated between 0.05 and 0.17 m per day (Rhainds & Shipp, 2004). Differences in *F. occidentalis* abundance between fertilization treatments could be attributed to thrips aggregation on highly fertilized plants rather than elevated reproductive rates. However, in a previous study using cages to prevent thrips movement between fertilization treatments (Chau et al., 2005), we showed that reproduction by *F. occidentalis* can produce differences in thrips abundance similar to what was observed for this study.

Fertilization influences not only thrips population abundance but also production time of chrysanthemum (Chau et al., 2004, 2005). Our study demonstrated that manipulation of fertilization level either lengthened or shortened production time. Production time shortened from 91 to 82 days when fertilization increased from 20 to 200% of the recommended level. Lowering fertilization level to 50% of the recommended level lengthened production time from 84 to 88 days. Four days amounts to less than a 5% increase in total production time and could be easily incorporated into production or delivery schedules for commercial growers of potted mum. A slight increase in production time would be an acceptable trade-off if thrips damage and insecticide treatments were substantially reduced.

Manipulation of fertilization would be a useful tactic for managing *F. occidentalis* if plant productivity and postproduction longevity are not significantly compromised. We showed that lowering fertilization level to 50% would not adversely affect chrysanthemum growth and productivity. Fertilization improves chrysanthemum growth and development by providing essential macro- and micronutrients. Although total nitrogen content of chrysanthemum leaf tissues increases with higher levels of fertilization (Chau et al., 2005; Davies et al., 2005), fertilization levels from 50 to 100% provided plants with leaf nitrogen within the range (45–60 g kg^{-1}; Lunt et al., 1964; Mills & Jones, 1996) needed to attain acceptable market quality for potted chrysanthemum (Chau & Heinz, 2006).

Postproduction longevity, or keeping quality, is another important aspect to consider when manipulating fertilization input for potted chrysanthemum. Plant variety, temperature, light level, fertilization, shipping conditions, and interior light level all influence postproduction longevity of potted chrysanthemum (Wesenberg & Beck, 1964; Roude et al., 1991; Nell, 1993). We found no differences in postproduction longevity (ranging from 26 to 27 days) when chrysanthemums (cv. 'Charm') were fertilized with greater than 50% of the recommended level. Although we showed that fertilization could be reduced to 50% of the recommended level without affecting plant growth and flower production, the postproduction longevity was reduced slightly to 24 days. Nell & Barrett (1990) showed that postproduction longevity of chrysanthemum varies greatly between chrysanthemum varieties, ranging from 13 (cv. 'sunburst Spirit') to 27 days (cv. 'Iridon'). Our findings showed that postproduction longevity for 'Charm' ranges from 24 to 27 days when plants were provided with optimal fertilization, ranging from 50 to 100%.

From an economic perspective, lowering fertilization to 50% of the recommended level should reduce fertilizer costs. Based on the rate and volume of fertilizer used in our study, fertilizer cost per pot was US$ 0.016 at the recommended level (375 p.p.m. N) or US$ 0.011 at 50% of the recommended level. Large commercial nurseries in the USA produce on average 108,000 potted flowering plants per year (Jerardo, 2005). Lowering fertilization to 50% of the recommended level would reduce their annual fertilizer cost from US$ 1728.00 to US$ 1188.00. However, fertilizer and chemical costs usually account for less than 3% of total production costs in North America while labor may account for up to 41% (Chaudhary, 2001; Uva & Richards, 2003).

Lowering fertilization may have limited impact on total production costs but it should consistently reduce fertilizer input into the production system and thus lessen nonpoint source runoff and contamination of surface and ground water. Due to environmental concerns and governmental regulation such as the Federal Clean Water Act (Yeager et al., 1997; Lea-Cox & Ross, 2001), best management practices that reduce inputs and minimize nonpoint source runoff are becoming a necessity for commercial operations in the USA. In Europe, there is considerable demand for flowers and ornamental plants produced by 'environment-friendly' methods. Certification programs such as Milieu Programma Sierteelt in the Netherlands enable growers to market their products as 'environment-friendly' and provide growers with incentives to reduce production inputs and minimize environmental impact (Hamrick, 2000). Manipulation of fertilization could also be implemented with biological control and host plant resistance to minimize insecticide usage and further reduce harmful chemicals in runoff.

To summarize, we have demonstrated that lowering fertilization to 50% of the recommended level reduced thrips population abundance without significant compromises to either the production or the quality of potted chrysanthemum. Two important advantages of lowering fertilization level to 50% of the recommended were (1) a 44% reduction in mean *F. occidentalis* abundance and (2) a significant reduction in fertilizer input for the production system. In this study, we examined only the effect of varying fertilization levels on thrips population growth and crop production, but future studies should also investigate its effects on crop damage by thrips feeding. Nutrient ratio and fertilizer source can influence insect growth and development (Bentz et al., 1995; Busch & Phelan, 1999; Jansson & Ekbom, 2002) and could be important tools for fine-tuning our strategies for pest management. If manipulation of fertilization can be implemented with other management tactics, we would not only improve control of *F. occidentalis* but also reduce contamination of the environment by agricultural runoff.

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