Advances in Crop Science and Technology

Chen et al., Adv Crop Sci Tech 2014, 2:4
http://dx.doi.org/10.4172/2329-8863.1000145

Research Article Open Access

# Effects of Nitrogen and Phosphorous Fertilization on Western Flower Thrips Population Level and Quality of Susceptible and Resistant Impatiens

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**Abstract**

Impatiens (Impatiens wallerana) cultivars ‘Super Elfin Red’ and ‘Dazzler Violet’, resistant or susceptible, respectively, to western flower thrips (Frankliniella occidentalis) were grown under 112 or 336 mg·L-1 N in combination with 10, 20, or 40 mg·L-1 P to investigate the effect of fertilization and host plant resistance on thrips population level and plant quality. Half of the plants were inoculated with thrips at two weeks after fertigation treatments began (WAT) and sampled at 4 and 8 WAT. For thrips-free plants, both N rates and the two higher P rates resulted in market-quality plants with various tissue N and P concentrations. Plant quality was lower in thrips-infested plants due to thrips damage to foliage as distortion on expending leaves and browning on edges of fully expended leaves. Higher numbers of adult and immature thrips were found in ‘Dazzler Violet’ than ‘Super Elfin Red’. However, distortion index, which represented degree of distortion on young leaves, was higher in the resistant cultivar, and the two cultivars had similar quality ratings at 8 WAT. For both cultivars, N had no effect on thrips population, and plants fertilized with 20 or 40 mg·L-1 had higher number of thrips than the low rate. However, percentage of damaged leaf area, which represented the severity of browning, was found higher in plants fertilized at the low P rate. As a result, both cultivars fertilized with higher P rates had better plant quality although these plants had more thrips. Therefore, when infestation level is moderately low, i.e. 10 thrips per plant, plant nutrient status favoring thrips development may not necessarily result in lower plant quality. The final outcome of plant marketability is a combination of plant growth, thrips damage, and the ability of plants to compensate for pest damage.

## Introduction

The western flower thrips (WFT), *Frankliniella occidentalis* Pergande, is one of the most serious pests of ornamental crops as well as many other crops throughout the world [1]. Both adult and immature feed on plants by piercing and rasping leaf or petal surface and withdrawing sap that exudes from injured cells, causing aesthetic injuries including lesions, discoloration, distortion, and dropping of leaves and floral buds [2]. In addition, WFT vectors impatiens necrotic spot virus (INSV) and several strains of tomato spotted wilt virus (TSWV) [3]. Thrips management in greenhouse productions has traditionally relied on a limited number of insecticides, and thrips resistance to carbamates, organophosphates, pyrethroids, and spinosad has been well documented [4-6]. Alternative approaches that incorporate available cultural, biological, and chemical measures are needed for effective crop protection as well as managing pest resistance development.

Host plant resistance to WFT have been identified in ornamental crops, i.e., chrysanthemum, eustoma [7], impatiens [8], miniature rose [9], cut rose [10], and verbena [11]. Warnock [8] reported significant lower level of WFT damage in resistant impatiens after being inoculated with 30 thrips and grown for eight weeks. Of these cultivars, some had high thrips population levels, indicating tolerance, while others had low thrips population levels, an indication of antibiosis. One of the possible mechanisms for host plant resistant is the content of secondary metabolic chemicals (i.e. phenols) in the plant tissue that might be altered by fertilization. However, whether or not production practices such as nitrogen (N) and phosphorous (P) fertilization rates would alter host plant resistance has not been studied for ornamental crops [12].

Previous research suggests that manipulating fertilization levels can impact thrips populations in row crops through changing hosts nutrient content [13]. Either positive or no effects of N fertilization has been reported for thrips. However, many of these reports are based on experiments where insect responses to plants deficient in N are compared to plants with sufficient or luxurious N concentrations [14,15]. Such results have limited application to commercially produced crops because N and P are more likely to be over-applied for a faster crop cycle and better economic returns [16]. Fewer studies have investigated insect population growth in response to P fertilization. Chen et al. [17] reported that a slight population increase was observed when tissue P concentration increased and became luxurious in impatiens plants.

Impatiens is one of the top three warm season bedding plants, contributing a wholesale value of $62 million to the floriculture industry in 2011 (USDA NASS 2011 Floriculture Summary, 15-state data). Feeding and ovi position injuries caused by WFT on impatiens include distorted young leaves and brown areas on leaf edges. Level of injury is affected by cultivar and also growing stage because of WFT’s preference for nectar and pollen [17] thus flowering plants may have less damage on their foliage than plants at vegetative stages. If plant marketability is affected by cultivar, fertilization, and pest level, interactions among these factors need to be determined before they can

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**Received:** September 11, 2014; **Accepted:** October 08, 2014; **Published:** October 13, 2014

**Citation:** Chen Y, Story R, Samuel-Foo M (2014) Effects of Nitrogen and Phosphorous Fertilization on Western Flower Thrips Population Level and Quality of Susceptible and Resistant Impatiens. Adv Crop Sci Tech 2: 145. doi:10.4172/2329-8863.1000145

be manipulated for thrips management. Therefore, the objective of this study was to determine the effects of N and P fertilization on WFT population level and damage in resistant vs. susceptible impatiens.

## Materials and Methods

The study was conducted at Louisiana State University Agricultural Center Hammond Research Station, Hammond, LA in 2010. 'Super Elfin Red' and 'Dazzler Violet' seeds were sown in MetroMix300 potting mix (mixture of sphagnum peat moss and perlite, SunGro Horticulture Canada Ltd.) on 5 Mar. Seeds were not covered by potting mix and exposed to a natural photoperiod of about 14:10 day/night to germinate. Seedlings were grown in a greenhouse covered with 60% AlumiNet (Green-Tek, Dinuba CA) for three weeks and then individually transplanted to 4 inch (8.5-cm) square pots (280 ml) on 2 April using MetroMix360, which was formulated with sphagnum peat moss, coarse perlite, and fine bark. The potting mix was amended with 4.7 kg dolomitic limestone per $m^3$ to adjust pH. Plants were placed into thrips-proof cages, one plant per cage to avoid natural infestation by thrips and other pests. Cages were constructed from 5-gal (19 L) plastic buckets with four windows, each 6 x 12 inch, cut into the sidewall then covered with no-thrips screen (GreenTek, Janesville, WI) and sealed with silicone. The top of the bucket was covered by a muslin cloth and held in place by rubber bands. The study was conducted in a research greenhouse with temperatures set at 26°C/20°C day/night. Actual temperature and relative humidity in the greenhouse were recorded by HOBO sensors (Onset Computer Corp., Bourne, MA). During the 8-week experiment, temperatures ranged from 18.8 to 31.4°C with an average daily temperature of 24.5 ± SD of 3.1°C; and the relative humidity ranged from 23.8% to 93.6%, with an average of 56.2% ± 18.4%.

Application of six experimental nutrient solutions started on the day of transplant (week 1) as combinations of 112 or 336 $mg \cdot L^{-1}$ N by 10, 20, or 40 $mg \cdot L^{-1}$ P. These rates were chosen because previous experiments had shown that applications of N and P within these ranges produced commercial quality impatiens [17]. The selected N rates are also close to those recommended by Dole and Wilkins [18] for impatiens. Nitrogen sources were $NO3^-$ and $NH4^+$ at a rate of 3:2. Phosphorous source was $KH_2PO_4$ and other essential and micro nutrients were held constant among solutions at the following rates: K at 6 mM, Ca at 0.65 mM, Mg at 1.5 mM, Fe at 1.5 $mg \cdot L^{-1}$, Cu at 0.24 $mg \cdot L^{-1}$, Zn at 0.19 $mg \cdot L^{-1}$, and Mn at 0.43 $mg \cdot L^{-1}$.

Water source for the nutrient solution was municipal (Hammond LA) with a pH at 8.3 and alkalinity at 31 $mg \cdot L^{-1}$. Fertigation was delivered by pumping single-strength nutrient solutions to individual pots inside sealed cages through spaghetti tubing. A submersible pump (8.8 L per min, Little Giant Pump Co., Oklahoma City, Ok) was housed in 120 L containers filled with one of the six nutrient solutions. Timing of fertigation was determined by weighing six non-experimental plants that were grown under the same cultural practices. Benches were fertigated when the weight of sample pots dropped by 20% ± 5% from their container capacity (weight after irrigation and leaching) due to water loss. This procedure resulted in plants receiving fertilizer solution about twice per week at the beginning to almost daily as plants reached marketable sizes. Leaching fraction was maintained at ~15% at each fertigation.

A virus-free WFT colony was obtained from the Department of Entomology, Kansas State University and reared on green beans in plastic containers (20×14×10 cm) at 24°C and relative humidity of 50%. Adult and immature stages were maintained in separate containers to produce large numbers of even-aged thrips. Prior to inoculation, containers with thrips were placed in a refrigerator at 6°C for 20 minutes to slow their movement. Plants were inoculated with ten female adults at two weeks after fertigation began. Cages were resealed after inoculation.

The experimental design was a completely randomized block design (CRBD) with a total of 24 treatment combinations [2 N × 3 P × 2 cultivar × 2 thrips densities (0 and 10)] and 8 replications (blocks). The 8 replications were arranged on eight benches in a research greenhouse. The benches were arranged parallel to the cooling pads so that blocking accounted for the temperature gradient in the greenhouse. A total of 24 cages with 12 plants of each cultivar were arranged on each bench, with six nutrient treatments and two inoculation densities randomly assigned to them.

Four replications were each sampled on 4 May and 2 June (weeks 4 and 8). At the time of sampling, a plant was removed from its cage and placed in a plastic container (34 × 25 × 15 cm). Plant heights, widest width, perpendicular width to the widest width, and number of flowers were recorded. An overall quality rating (QR) was given to the plant using a scale from 1 to 10 by taking into consideration of plant size and form, leaf greenness and glossiness, and number and size of flowers. Plants meeting commercial size were assigned a rating between 7 and 10 and then classified into one of three market ratings (MR): "premium" that plants with highest market quality (MR ≥2, QR between 9 and 10), "Discounted" plants that likely to be marketed at a lower price (MR ≥ 1, QR between 8 and 9), and "unmarketable" plants that likely will be discarded by growers (MR ≤ 1, QR between 7 and 8).

Another typical injury symptom caused by WFT on many ornamental plants is distortion on young leaves, and a distortion index was developed and used on ivy geraniums to describe this injury [19]. Leaf distortion in impatiens caused by thrips feeding is usually observed on young leaves that cannot expand normally because of feeding scars. Each plant was assessed for the severity of distortion on three stems using a rating scale of 0 to 3 to represent no distortion (0), and slight (1), moderate (2) and severe (3) distortion. Total distortion was then calculated as distortion index (DI) which was the average from the ratings of three stems.

Plants were then destructively sampled for thrips by cutting each plant at its base and laying it horizontally in a container that was divided into three sections by inserting two plastic boards across the width of the container. Each stem was then cut based on these leaf categories: stem with young leaves (Y), stem with fully-expanded leaves (FE), and stem with old leaves (O) and put into the three sections in the container. The container was shaken for ten times and thrips dislodged into each section was counted by a tally counter. The Y stratum with the meristems was then washed with a 48% ethanol stream and then filtered and checked under a 10x microscope (Micro Master, Fisher, USA) for thrips. Thrips in flowers and buds were individually counted by destructively peeling back petals. Numbers of adult and immature (nymph, pre-pupae, and pupae) stages were recorded separately, and total WFT number was the sum of adult and immature.

Leaves were then detached from stems and scanned by a HP ScanJet 3100C (Hewlett-Packard Co., Palo Alto, CA) and the acquired images were analyzed for Percent Damaged Area (PDA) as described by Chen and Williams [20] that can be distinguished from normal leaf tissue by digital imaging and computer software [20]. Damaged area of a plant is quantified and better correlated with thrips population than subjective visual damage ratings. The three strata were scanned and analyzed separately. The PDA for the entire plant was computed as total damaged area divided by total leaf area.

After the images were acquired, leaf tissue samples were collected from FE leaves, which can best represent plant nutrient status at the time of sampling. Tissue samples were washed and dried at 70°C for 48 h, then ground in a stainless steel Wiley mill to a particle size<1 mm. Tissue analyses were conducted by Louisiana State University Soil Testing and Plant Analysis Laboratory (Baton Rouge, LA). Tissue N concentration was determined by an LECO TruSpec CN nitrogen analyzer (LECO Corp., St. Joseph, MI), and tissue P was determined by ICP-emission spectroscopy (Fisons Instruments, Dearborn, MI).

All data were subjected to normality check and those that failed were transformed using appropriate means to improve normality based on suggestions from Hartwig and Dearing [22]. LSMEANS were back-transferred after analysis. Effects of treatment factors on thrips population levels were tested by PROC MIXED and the LSMEANS statement was used to compute means for each effect (SAS software v 12.1, SAS Institute, 2001). The MIXED model for analysis included treatment factors and their interactions; block, block x N x P, and block x cultivar x N x P were included as random effects.

## Results and Discussions

For all dependable variables, interactions among treatment factors were not significant or significant but did not affect the main effects of treatment factors.

**Plant growth and tissue N% and P%:** When comparing the two cultivars, although 'Super Elfin Red' had greater DW than 'Dazzler Violet' at 4 weeks after fertigation treatment (WAT), they had similar DW at 8 WAT and were similar in plant size (SI) at 4 and 8 WAT (Table 1). 'Dazzler Violet' was higher in tissue P% than 'Super Elfin Red' at 4 WAT and was higher in both N% and P% at 8 WAT. 'Super Elfin Red' had more flowers than 'Dazzler Violet' at 8 WAT (13 vs. 3.2).

Nitrogen rate at 336 mg·L$^{-1}$ resulted in similar plant SI and DW but higher tissue N% at both sample dates compared to 112 mg·L$^{-1}$ and (Table 1). Tissue P% was affected by N rate at 8 WAT that plants fertilized with the higher N rate had slightly higher tissue P concentration than those fertilized at the low N rate. This is possibly a result of more update of both N and P at higher N rate. Similarly, planted fertilized at higher P rates had higher tissue N% than those fertilized at lower P rates, i.e. 10 mg·L$^{-1}$.

Phosphorus at the low rate (10 mg·L$^{-1}$) resulted in smaller plants, lower tissue N% and P%, and fewer flowers compared with plants fertigated at higher P rates at both sample dates (Table 1). Therefore, the 2N x 3 P nutrient treatments resulted in similar marketable plants (except those at the low P rate) but varying tissue N% (ranging from 3.5% to 4.3% at 4 WAT and 3.3% to 4.2% at 8 WAT) and P% (from 0.21% to 0.52% at 4 WAT and 0.16% to 0.48% at 8 WAT).

Inoculating 10 thrips at 2 WAT did not affect plant growth and flowering at 4 or 8 WAT, suggesting that thrips infestation at this level does not adversely affect growth and flowering of both cultivars.

More thrips were found on 'Dazzler Violet' than on 'Super Elfin Red' especially the number of immature at 4 WAT (20.2 vs. 9.2) and both adults and immature at 8 WAT (22.8 vs. 9.1 and 30.8 vs. 12.4, Table 2). This confirmed that 'Super Elfin' impatiens is more resistant to thrips. Evaluation of onion thrips on onion cultivars grown in the field showed low population level on resistant cultivars, indicating a combination of antibiosis and/or antixenosis [22]. In the current study, because thrips were inoculated onto plants held in individual cages and was not given a choice between the two cultivars, the low population level found on 'Super Elfin' indicated antibiosis as the possible mechanism for resistance, meaning that 'Super Elfin Red' was not as suitable of a host as 'Dazzler Violet'. A coincidence was that tissue P% in Dazzler Violet' was higher than 'Super Elfin Red' at both sample dates (0.42 vs. 0.32% and 0.38 vs. 0.24%; (Table 1). Similar results was reported by Zhi et al. [22] that resistant impatiens 'Cajun Carmine' had significant lower number of WFT and two spotted spider mite (*Tetranychus urticae* Koch) compared to a susceptible cultivar 'Impulse Orange', which also indicated antibiosis. However, tissue nutrient concentrations were not measured in their study.

Percent Damaged Area was an indication of thrips damage. 'Dazzler Violet' had higher PDA than 'Super Elfin Red' at 8 WAT, possibly due to the higher number of thrips on this cultivar. 'Super Elfin Red' had higher DI in both inoculated and thrips-free plants comparing with inoculated and thrips-free 'Dazzler Violet', respectively (data not shown). As a result, across thrips inoculation rate and fertilization levels, 'Super Elfin Red' and 'Dazzler Violet' had similar visual QR and MR at both sample dates (Table 2).

Across cultivar and inoculation rate, N fertilization had no effect on thrips population at 4 WAT, however, number of immature was higher in plants fertilized with the low rate than those with 336 mg·L$^{-1}$ N (25 vs. 18, Table 2). Hunt et al. [12] reported that N ranging from 50 to 100 mg·L$^{-1}$ was suitable for WFT development than lower or higher rates. A moderate N rate is more favorable for pest population growth because N is not a limiting factor, while at relatively high N rates; accumulation of certain secondary metabolites, i.e., phenolic acids, can negatively impact insect growth and reproduction.

Effect of P on WFT population level was not significant at 4 WAT, however, at 8 WAT, for both cultivars, number of adult were significantly higher in plants fertilized with 20 or 40 mg·L$^{-1}$ than those fertilized with the low P rate (19 and 18 vs. 12, Table 2). Numbers of immature were higher in plants fertilized with 20 mg·L$^{-1}$ than those at 10 mg·L$^{-1}$ P (25 vs. 18) but similar to those fertilized at 40 mg·L$^{-1}$. Chen et al. [17] reported similar P effects with 'Dazzler Violet', where plants fertilized with 40 mg·L$^{-1}$ P had marginally more adult and immature WFT than plants fertilized at 10 mg·L$^{-1}$. Our results indicate that this trend was consistent in both resistant and susceptible cultivars.

The percentage of damaged leaf area (PDA) of thrips-free plants was about 1.1% at both sample dates indicating that there are other factors affecting PDA in addition to thrips damage. Plants inoculated with 10 adult thrips developed higher PDA than thrips-free plants, and increased from 3.8% at 4 WAT to 5% at 8 WAT (Table 2). These PDA values represented minor but noticeable browning on leaf edges. 'Dazzler Violet' had higher PDA than 'Super Elfin Red' at 8 WAT possibly because of higher numbers of thrips on this cultivar. Fertilization had no effect on PDA at both sample dates except that plants fertilized with 20 mg·L$^{-1}$ P had lower PDA than those at 10 mg·L$^{-1}$ at 4 WAT despite similar population levels at these rates. A possible explanation is that plants fertilized at higher P rates may provide higher nutrients per feeding area thus reduced the overall leaf area needed for supporting similar population levels.

The distortion index is a measure of how easily distorted young leaves can be noticed by bare eyes. Inoculation with 10 thrips did not affect distortion index (DI) in young leaves until 8 WAT (Table 2). Because DI was also found in thrips-free plants (i.e., 0.49 vs. 0.68 in thrips-free and inoculated plants, respectively), apparently, some

| Treatment$^{z}$ | 4 WAT | | | | 8 WAT | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | SI cm | DW g | N% | P% | SI cm | DW g | Flower no. | N% | P% |
| Cultivar | | | | | | | | | |
| Super Elfin Red | 20.3 | 4.1 $^{a}$ | 3.9 | 0.32 $^{b}$ | 24.3 | 7.9 | 13 $^{a}$ | 3.6 $^{b}$ | 0.24 $^{b}$ |
| Dazzler Violet | 19.3 | 3.6 $^{b}$ | 3.9 | 0.42 $^{a}$ | 23.7 | 7.4 | 3.2 $^{b}$ | 3.8 $^{a}$ | 0.38 $^{a}$ |
| LSD$_{.05}^{y}$ | NS | 0.5 | NS | 0.03 | NS | NS | 1.2 | 0.1 | 0.03 |
| N | | | | | | | | | |
| 112 | 19.9 | 3.7 | 3.5 $^{b}$ | 0.38 | 24.2 | 7.7 | 7.6 | 3.3 $^{b}$ | 0.29 $^{b}$ |
| 336 | 19.8 | 3.9 | 4.3 $^{a}$ | 0.36 | 23.9 | 7.6 | 7.2 | 4.2 $^{a}$ | 0.33 $^{a}$ |
| LSD$_{.05}^{x}$ | NS | NS | 0.1 | NS | NS | NS | NS | 0.1 | 0.03 |
| P | | | | | | | | | |
| 10 | 17.9 $^{b}$ | 3.2 $^{b}$ | 3.7 $^{b}$ | 0.21 $^{c}$ | 22.0 $^{b}$ | 6.4 $^{b}$ | 6.6 $^{b}$ | 3.5 $^{b}$ | 0.16 $^{c}$ |
| 20 | 20.8 $^{a}$ | 4.2 $^{a}$ | 3.9 $^{a}$ | 0.38 $^{b}$ | 25.5 $^{a}$ | 8.7 $^{a}$ | 9.0 $^{a}$ | 3.8 $^{a}$ | 0.28 $^{b}$ |
| 40 | 20.7 $^{a}$ | 4.0 $^{a}$ | 4.0 $^{a}$ | 0.52 $^{a}$ | 24.6 $^{a}$ | 7.8 $^{a}$ | 8.4 $^{a}$ | 3.9 $^{a}$ | 0.48 $^{a}$ |
| LSD$_{.05}^{w}$ | 1.7 | 0.6 | 0.1 | 0.04 | 1.7 | 1.0 | 1.9 | 0.1 | 0.03 |
| Thrips | | | | | | | | | |
| 0 | 19.8 | 3.8 | 3.8 | 0.33 | 24.1 | 7.8 | 7.6 | 3.7 | 0.28 |
| 10 | 19.8 | 3.8 | 3.9 | 0.38 | 24.0 | 7.6 | 6.4 | 3.8 | 0.31 |
| LSD$_{.05}^{v}$ | NS | NS | NS | NS | NS | NS | NS | NS | NS |

**Table 1:** Plant size index (SI), dry weight (DW), number of flowers, and tissue N and P concentrations in the youngest fully expended leaves of ‘Super Elfin Red’ and ‘Dazzler Violet’ impatiens at 4 or 8 weeks after transplant (WFT) and being fertigated with 2N x 3P nutrient solutions and inoculated with 10 thrips or kept thrips-free.

$^{z}$Interactions among treatment factors were not significant for all dependent variables.
$^{y}$Least significant difference of the least square means of each cultivar, α=0.05, n=48.
$^{x}$Least significant difference of the least square means of each N rate, n=32.
$^{w}$Least significant difference of the least square means of each P rate, n=48.
$^{v}$Least significant difference of the least square means of each thrips inoculation rate, n=48.

| Treatment$^{z}$ | 4 WAT | | | | | | 8 WAT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Adult | Immature | PDA% | DI (0 to 3) | QR (1 to 10) | MR (1 to 3) | Adult | Immature | PDA% | DI (0 to 3) | QR (1 to 10) | MR (1 to 3) |
| Cultivar | | | | | | | | | | | | |
| Super Elfin Red | 2.0 $^{b}$ | 9.2 $^{b}$ | 3.0 | 0.99 $^{a}$ | 7.9 | 2.0 | 9.1 $^{b}$ | 12.4 $^{b}$ | 3.7 $^{b}$ | 1.03 $^{a}$ | 7.8 | 2.1 |
| Dazzler Violet | 3.3 $^{a}$ | 20.2 $^{a}$ | 3.3 | 0.31 $^{b}$ | 7.7 | 2.0 | 22.8 $^{a}$ | 30.8 $^{a}$ | 4.7 $^{a}$ | 0.30 $^{b}$ | 7.7 | 2.0 |
| LSD$_{.05}^{y}$ | 0.7 | 3.3 | NS | 0.14 | NS | NS | 3.6 | 5.1 | 0.7 | 0.14 | NS | NS |
| N | | | | | | | | | | | | |
| 112 | 2.8 | 16.0 | 3.30 | 0.70 | 7.7 | 2.1 | 17.7 | 25.0 $^{a}$ | 425 | 0.68 | 7.6 | 2.1 |
| 336 | 2.4 | 13.4 | 3.00 | 0.57 | 7.9 | 1.9 | 14.2 | 18.2 $^{b}$ | 4.11 | 0.60 | 7.9 | 1.9 |
| LSD$_{.05}^{x}$ | NS | NS | NS | NS | NS | NS | NS | 5.1 | NS | NS | NS | NS |
| P | | | | | | | | | | | | |
| 10 | 2.4 | 13.0 | 3.49 $^{a}$ | 0.66 | 7.4 $^{b}$ | 1.9 $^{b}$ | 11.5 $^{b}$ | 17.5 $^{b}$ | 4.37 | 0.65 | 7.2 $^{c}$ | 1.8 $^{b}$ |
| 20 | 2.3 | 13.5 | 2.78 $^{b}$ | 0.55 | 8.0 $^{a}$ | 1.9 $^{b}$ | 18.5 $^{a}$ | 24.7 $^{a}$ | 3.84 | 0.64 | 8.2 $^{a}$ | 2.0 $^{b}$ |
| 40 | 3.1 | 17.8 | 3.19 $^{ab}$ | 0.69 | 8.0 $^{a}$ | 2.3 $^{a}$ | 17.9 $^{a}$ | 22.5 $^{ab}$ | 4.35 | 0.63 | 7.8 $^{b}$ | 2.3 $^{a}$ |
| LSD$_{.05}^{w}$ | NS | NS | 0.54 | NS | 0.3 | 0.2 | 4.4 | 6.2 | NS | NS | 0.4 | 0.25 |
| Thrips | | | | | | | | | | | | |
| 0 | 0.2 $^{b}$ | 1.5 $^{b}$ | 1.1 $^{b}$ | 0.54 | 8.1 $^{a}$ | 2.1 $^{a}$ | 0.5 $^{b}$ | 0.5 $^{b}$ | 1.1 $^{b}$ | 0.49 $^{b}$ | 8.2 $^{a}$ | 2.1 $^{a}$ |
| 10 | 3.4 $^{a}$ | 19.1 $^{a}$ | 3.8 $^{a}$ | 0.66 | 7.7 $^{b}$ | 1.6 $^{b}$ | 19.8 $^{a}$ | 26.5 $^{a}$ | 5.0 $^{a}$ | 0.68 $^{a}$ | 7.7 $^{b}$ | 1.6 $^{b}$ |
| LSD$_{.05}^{v}$ | 0.8 | 3.9 | 0.5 | NS | 0.3 | 0.2 | 4.5 | 6.4 | 0.8 | 0.18 | 0.4 | 0.3 |

**Table 2:** Number of adult and immature thrips per plant, distortion index (DI), percent damage area (PDA), visual quality rating (QR) and market rating (MR) of ‘Super Elfin Red’ and ‘Dazzler Violet’ impatiens at 4 or 8 weeks after transplant (WFT) and being fertigated with 2N x 3P nutrient solutions and inoculated with 10 thrips or kept thrips-free.

$^{z}$Interactions among treatment factors were not significant for all dependent variables.
$^{y}$Least significant difference of the least square means of each cultivar, α=0.05, n=48.
$^{x}$Least significant difference of the least square means of each N rate, n=32.
$^{w}$Least significant difference of the least square means of each P rate, n=48.
$^{v}$Least significant difference of the least square means of each thrips inoculation rate, n=48.

distortion was caused by environmental conditions. For example, we observed that 'Super Elfin Red' tends to have more distorted young leaves when grown at low temperatures. Correlation analyses indicated that there was no relationship between DI and thrips numbers (p=0.3822) with a data set including both cultivars and N/P rates. Therefore, PDA, which was significantly correlated to total number of thrips (*p*=0.0325), is a more relevant measurement for quantifying thrips damage.

Thrips feeding negatively affected plant visual quality rating (QR) compared with thrips-free plants at 4 and 8 WAT (~7.7 vs. 8.2, Table 2). Plant marketability was also affected by thrips injury in that, thrips-infested plants were of lower MR than thrips-free plants and had to be marketed at a discounted price (MR<2). Therefore, to avoid economic loss in both cultivars, control action is needed within two weeks of infestation with 10 adults per plant. This is consistent with the economic injury threshold recommended for impatiens by Frey [23].

Nitrogen fertilization had no effect on QR and MR, which was expected because of similar plant growth, PDA, and DI between the two N rates. Phosphorus rate at 40 mg·L$^{-1}$ resulted in higher MR than 10 or 20 mg·L$^{-1}$ although plants fertilized with 40 mg·L$^{-1}$ had more thrips than those fertilized at 10 mg·L$^{-1}$, suggesting that plants having higher tissue P% may be able to sustain higher pest pressure than those with lower tissue P% without showing more severe damage. Another possibility is that plants having higher tissue P% may be able to compensate for thrips damage better than those having low tissue P%. Thus This manipulate P fertilization might provide an advantage to IPM programs where it takes longer for bio pesticides to be effective, or when a low pest number is needed to maintain biological control agents on crops to be protected from WFT damage.

Population distribution of WFT on both cultivars varied between the two sample dates because plants were at vegetative growth at 4 WAT, and both cultivars began to flower at 8 WAT with the resistant 'Super Elfin Red' having more flowers (Table 1). Therefore, a larger portion of the population (both adult and immature) was found in 'Super Elfin Red' flowers than 'Dazzler Violet' at 8 WAT (Figure 1). Preference for flowers (nectar and pollen) was reported in impatiens [17], tomato [24], and cucumber [25]. Among the three leaf strata, more adult and immature thrips were found in FE than in Y or O (Figure 1). Therefore, thrips sampling plan should consider these distribution patterns for various growing stages of the crop. For example, FE leaves can be sampled for thrips monitoring at vegetative growing stage, and flowers can be sampled to determine population level when plants are in full bloom.

In summary, fertilizer applications with N from 112 to 336 mg·L$^{-1}$ and P from 20 to 40 mg·L$^{-1}$ can be used to produce quality 'Super Elfin Red' and 'Dazzler Violet' impatiens. Nitrogen had no positive effect on thrips population at these rates, while P rates resulted in more numbers of thrips compared to a lower rate at 10 mg·L$^{-1}$ which did not grow quality plants. Resistant cultivar 'Super Elfin Red' had significantly less number of thrips and less leaf browning than the susceptible cultivar 'Dazzler Violet'. Plant quality however, was an outcome from the combined effects of plant nutrient status and pest damage and was similar between cultivars and N rates, and higher in thrips-free and plants fertilized at 20 mg·L$^{-1}$ [26-28]. Based on these results, we would recommend using resistant cultivars in combination with P rates at about 20 mg·L$^{-1}$ for an impatiens IPM program.

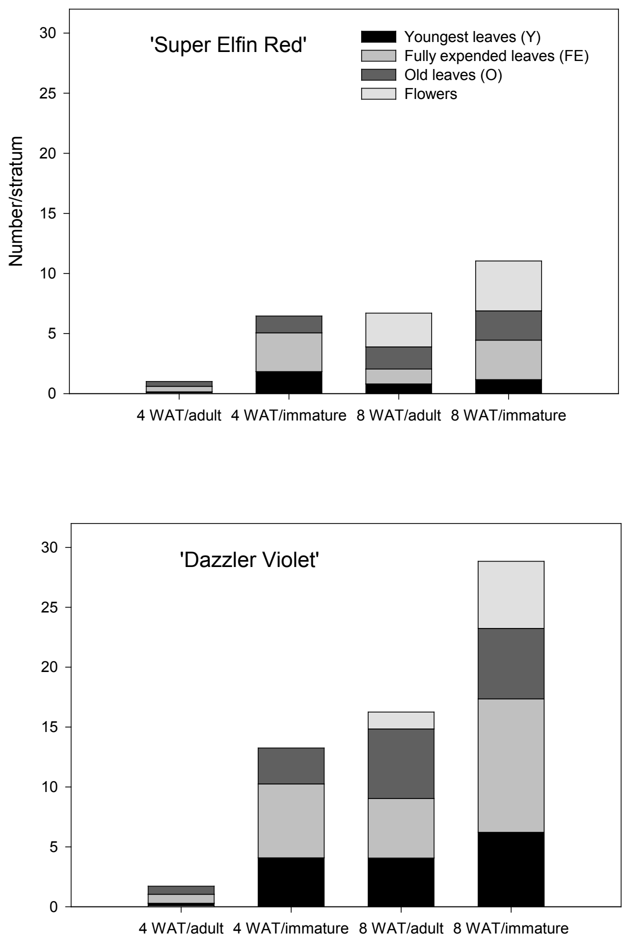


**Figure 1:** Thrips distribution among three leaf strata: young (Y), fully expended (FE), and old (O) at 4 weeks after transplant (WAT), and among leaf strata and flowers at 8 WAT in 'Super Elfin Red' and 'Dazzler Violet' impatiens.

**Acknowledgement**

We thank Joey Quebedeaux and Ashley Edwards for technical assistance, and Ball Horticultural Company for providing impatiens seeds. This work was financially supported by the USDA NIFA Pest Management Alternative Program Grant no: 2009-34381-20019.

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**Citation:** Chen Y, Story R, Samuel-Foo M (2014) Effects of Nitrogen and Phosphorous Fertilization on Western Flower Thrips Population Level and Quality of Susceptible and Resistant Impatiens. Adv Crop Sci Tech 2: 145. doi:10.4172/2329-8863.1000145