ABSTRACT

BUCKELEW, JULIANA KIRSTEN. Eastern Black Nightshade (*Solanum ptycanthum* Dun.) Management in Plasticulture Tomato (*Lycopersicon esculentum*). (Under the direction of David W. Monks)

Tomato production in North Carolina depends upon plastic mulch for increased total plant growth, earlier flowering, and earlier yield of tomato. Components of the plasticulture system include raised beds, plastic mulch, drip fertigation, and methyl bromide fumigation for pest control. With the phase-out of methyl bromide by the EPA, in-row weed growth will likely increase in this production system. Eastern black nightshade is a solanaceous annual weed that infests tomato. It is difficult to control without injuring tomato because of similar growth habit and physiology. Research was conducted in 2003 and 2004 to evaluate eastern black nightshade management and postemergence directed control of weeds that infest tomatoes in North Carolina.

Field experiments were conducted to determine density-dependent effects of eastern black nightshade season-long interference on tomato yield loss when growing in-row with plasticulture tomato. Eastern black nightshade was transplanted at densities 0, 1, 2, 3, 4, and 5 per planting hole. Percent yield loss for jumbo grade fruit, the premium grade, as affected by eastern black nightshade density followed a rectangular hyperbola model. Number and weight of cull, medium, and large grades did not differ by any density. Mean number and weight comparisons of extra large, jumbo, marketable, and total fruit categories showed a reduction for densities 1 to 5 weeds per hole from the weed-free, but no difference among densities 1 to 5 weeds per hole. The economic threshold for jumbo grade was one weed per 11.25 m of row (with 45 cm crop spacing). In additional field experiments, the effect of eastern black nightshade on tomato yield loss growing in-row with plasticulture tomato, as

well as eastern black nightshade berry production and seed viability were determined. Eastern black nightshade was transplanted at 1, 2, 3, 4, 5, 6, and 12 weeks after tomato planting (WAP) and remained until tomato harvest, or was established at tomato planting and removed at 2, 3, 4, 5, 6, and 8 and 12 WAP to determine the critical weed-free periods. The critical weed-free period to avoid viable seed production was 3 to 6 WAP. No treatment differences in tomato yield were found in year 1. In year 2 at the second location, differences in the sum weight of extra large and jumbo grades occurred. The critical weed-free period to avoid greater than 20% yield loss for the sum weight of extra large and jumbo grades was 28 to 50 days after tomato transplanting, and was economically justified based on 2004 tomato prices during weeks harvested.

Field experiments were conducted in 2003 to identify those herbicides that were safe to tomato postemergence directed and in 2004 to determine the effect of these herbicides postdirected at various rates on tomato injury and control of apple of Peru (*Nicandra physolodes),* eastern black nightshade, fall panicum (*Panicum dichotomiflorum* Michx.), goosegrass (*Eleusine indica* (L.) Gaertn.), hairy galinsoga (*Galinsoga ciliata* (Raf.) Blake), ivyleaf morningglory (*Ipomoea hederacea* (L.) Jacq.), jimsonweed (*Datura stramonium* L.), johnsongrass (*Sorghum halapense* (L.) Pers.), large crabgrass, *(Digitaria sanguinalis* (L.) Scop.) Mexican groundcherry (*Physalis ixocarpa* Brot. ex Hornem.), pitted morningglory (*Ipomoea lacunosa* L.), redroot pigweed (*Amaranthus retroflexus* L.), sicklepod (*Senna obtusifolia* L.), velvetleaf (*Abutilon theophrasti)*. In 2003, cloransulam-methyl, flumioxazin, halosulfuron, imazamox, metribuzin, thifensulfuron, and trifloxysulfuron sodium were applied. With the exception of cloransulam-methyl at Clinton which caused 11% injury, cloransulam-methyl, flumioxazin and imazamox gave 24% or greater visual injury to tomato.

Likewise, marketable fruit weight was 16 to 71% of the nontreated check for these herbicides. Tomato was injured 5% or less by all rates of halosulfuron, metribuzin, thifensulfuron, and trifloxysulfuron sodium and yielded similar to tomato in the nontreated control for these treatments. Thus cloransulam-methyl, flumioxazin, and imazamox were too injurious to tomato and excluded from 2004 studies. In 2004, trifloxysulfuron sodium, metribuzin, thifensulfuron, and halosulfuron again caused no differences in tomato yield from the non-treated control. Trifloxysulfuron sodium controlled apple of Peru, eastern black nightshade, jimsonweed, and Mexican groundcherry. Thifensulfuron controlled redroot pigweed, velvetleaf, Mexican groundcherry, hairy galinsoga, and jimsonweed. Metribuzin and halosulfuron consistently provided excellent control of Mexican groundcherry, velvetleaf, redroot pigweed, hairy galinsoga, and jimsonweed. Metribuzin consistently provided excellent control of sicklepod, apple of Peru, and eastern black nightshade.

EASTERN BLACK NIGHTSHADE (*SOLANUM PTYCANTHUM* DUN.) MANAGEMENT IN PLASTICULTURE TOMATO (*LYCOPERSICON ESCULENTUM*)

by
JULIANA KIRSTEN BUCKELEW

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APPROVED BY:

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Chair of Advisory Committee

Dedicated to

Mary Biel

And the late

Harvey Biel, Ferenc and Etelka Beivel

For sharing their knowledge and passion for horticulture

BIOGRAPHY

Juliana Beiwel Buckelew is the third child of Ferenc and Marian Beiwel. She grew up in Davenport, Iowa and graduated from Davenport West High School in 1991. She graduated from Iowa State University in 1997 with a Bachelor of Science Degree in Horticultural Science. After graduation she was employed by Seed Savers Exchange in Decorah, Iowa. After marrying Lamar Buckelew in 1998, they moved to Milwaukie, Oregon. There she worked for Oregon State University as an ornamental nursery production research technician at North Willamette Research and Extension Center. In spring of 2002, she began her graduate studies under the direction of Dr. David Monks at North Carolina State University.

ACKNOWLEDGMENTS

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I am grateful to my family for their love, support, and encouragement. Thanks to Lamar for believing in me.

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JULIANA K. BUCKELEW and DAVID W. MONKS[2]

Abstract: Field experiments were conducted to determine density-dependent effects of eastern black nightshade season-long interference on tomato yield loss when growing in-row with plasticulture tomato. Eastern black nightshade was transplanted at densities 0, 1, 2, 3, 4, and 5 per crop plant hole in the plastic. Yield loss (%) for weight of cull, three, medium, large, or extra large grades did not vary at densities above zero. Likewise, marketable, total, or sum of large, extra large and jumbo grades, did not vary at densities above zero. However, for jumbo grade fruit, the premium grade, yield loss (%) did vary among densities above zero. Jumbo grade yield loss (%) as affected by eastern black nightshade density followed a rectangular hyperbola model. Estimated coefficients for *A* (maximum yield loss) and *I* (yield loss per unit density as density approaches zero) was 84 and 116, respectively. Mean yield comparisons for number and weight of extra large, jumbo, marketable, and total fruit categories showed a reduction (for densities 1 to 5 weeds per hole) from the weed-free yield, but no difference among densities above 0. Number and weight of cull, medium, and large grades did not differ by any density (among densities 0 to 5 weeds per hole). These observations suggest eastern black nightshade causes tomato quality loss. Values of large and extra large were not affected by eastern black nightshade density, but value of jumbo fruit and the value of the sum of

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[1] Submitted for publication March 23, 2005 and in revised form date.

[2] Graduate student and professor, Department of Horticultural Science, North Carolina State University, Raleigh, NC 27695.

large, extra large, and jumbo grade varied by the densities tested. The economic threshold for jumbo grade was one weed per 11.25 m of row (with 45 cm crop spacing).

Nomenclature: eastern black nightshade, *Solanum ptycanthum* (Dun.), SOLPT#[3]; tomato, *Lycopersicon esculentum.*

Additional index words: Additive, competition, economic threshold, interference, models, weed density.

Introduction

The plasticulture system combines raised beds, plastic mulch, drip fertigation, and methyl bromide fumigation to produce increased rate of basal branch appearance, total plant growth, early flowering, and early yield of tomato (Wien and Minotti 1987 and 1988). However, one disadvantage of this production system is the competition caused by weed establishment in the 9 to 10 cm diameter openings in the plastic next to tomato transplants (Monks et al. 1997). The phase-out of methyl bromide in 2005 (EPA 1990) will likely increase the probability of weed establishment within planting beds and increase the importance of this problem.

Solanaceous weeds like eastern black nightshade (*Solanum ptycanthum*) are closely related to tomato, so control of eastern black nightshade by herbicides is difficult without injuring tomato (Gorski and Wertz 1987). Nightshade has been shown to reduce yields in

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

bare ground tomato production (McGiffen et al. 1992, Perez and Masiunas 1990, Weaver et. al. 1987). Increased nightshade density caused a progressive decrease in transplanted and seeded tomato yields in a bare ground system (Weaver et al. 1987; McGiffen et al. 1992; McGiffen et al. 1994). Because close proximity of weed and crop can increase weed/crop interference (Monks and Oliver 1988; Pike et al. 1990), and plasticulture and bare ground systems differ in method of delivery of water and nutrients through drip fertigation, weed interference effects are likely different. Knowledge of the nature of interference of weeds such as eastern black nightshade density effects in plasticulture tomato is a likely consideration when developing a weed management program for tomato, however, no information could be found on weed density effects on crop yield loss in a plasticulture system. Thus, an additive study (Spitters and Van Den Bergh 1982) examined the effect of season-long interference of eastern black nightshade at varying densities on yield and quality of transplanted tomato in a plasticulture system.

Materials and Methods

Field studies were conducted in western North Carolina at the Mountain Horticultural Crops Research Station near Fletcher, NC (82.56 degrees W, 35.43 degrees N, elevation 631 m). In 2003, soil was a Bradson gravelly loam (clayey, oxidic, mesic Typic Hapludults) having pH 6.2 and humic matter 0.56%. Fertilizer was broadcast incorporated with 83, 214, and 138 kg N, P_20_5, K_2O ha^{-1}, respectively, before soil bedding and plastic mulch application. In 2004, field plots were established in a Comus fine sandy loam soil (coarse-loamy, mixed, mesic Fluventic Dystrochrepts) having pH 6.2 and humic matter 1.31%. Fertilizer was broadcast incorporated with 84, 316, and 185 kg N, P_2O_5, K_2O ha^{-1}, respectively, before soil bedding and plastic mulch application. Dolomitic lime was also incorporated at 2240 kg ha^{-1}. Both years weekly fertigation schedules and plasticulture practices were followed as recommended by North Carolina Cooperative Extension Service (Sanders et al. 1996).

Tomato transplants approximately 20 cm tall with 4 to 5 true leaves were hand planted June 4, 2003 and June 14, 2004 using a 6.5 cm diameter bulb planter to open the holes in the plastic. Within 24 h after tomato transplanting, eastern black nightshade seedlings with two true leaves were transplanted into the same planting hole as tomato. Eastern black nightshade transplants, sown approximately 18 d prior to planting using a 98 cell plug tray[4] containing potting media[5], were used to ensure uniformity. Other similar research has also used eastern black nightshade transplants (Croster and Masiunas 1998; McGiffen, et al. 1994; McGiffen and Masiunas 1992; McGiffen, Masiunas, and Hesketh 1992; McGiffen, Masiunas, and Huck 1992; Perez and Masiunas 1990). Eastern black nightshade seeds were collected near Vale, North Carolina in fall 2002. A plant specimen from this experiment was deposited at the North Carolina State University Plant Herbarium for taxonomic reference. All weed seedlings were transplanted approximately 3 cm from the tomato.

Plots were single-row plantings of fresh market, determinate cultivar 'Amelia'[6] tomato and eastern black nightshade plants at the designated density. Plots were 1.5 by 4.5 m in size. Row centers were 1.5 m apart; space between plants within the row was 45 cm. Of the ten plants per plot, the middle six were harvested and the outer two on each end were buffer plants. To avoid shading of neighboring plots, 91 cm were left between each plot within the row. Bed width was 70 cm at the base and 63 cm at the top. Height of the beds from base to ridge was approximately 16 cm. Row middles were maintained weed-free throughout the growing season by applying napropramide at 4.5 kg ha^{-1} after planting and paraquat at 0.6 kg ha^{-1} postemergence as needed. Weeds other than eastern black nightshade growing within the planting holes were controlled by hand removal.

Hand harvest began when approximately 5% of all fruit were at the physiological fruit stage of breaker. The stage was usually evident when a yellowish-tan star formed at the blossom end. Fruit stage at the subsequent harvests was breaker stage to red. The final harvest consisted of all fruit 5 cm in diameter and larger, regardless of color classification. All fruit were graded by hand and sized by machine according to United States standards for grades of fresh market tomato consisting of grades medium, large, extra-large, and jumbo (5 to 6.4, 6.4 to 7.3, 7.3 to 8.8, and greater than 8.8 cm in diameter, respectively) (Anonymous 1997). Three-grade fruits were of various sizes without serious damage or defects, but were not of first quality. Marketable fruit consisted of three, medium, large, extra large, and jumbo grades; total fruit consisted of these grades plus culls.

Four weed densities (0, 1, 2, and 3 weeds per hole) were evaluated in 2003, and six weed densities (0, 1, 2, 3, 4, and 5 weeds per hole) were evaluated in 2004. The experimental design was a randomized complete block design with six replications in 2003 and four in 2004.

Yield loss (%) weight data were subjected to ANOVA (SAS 1999), with year nested within block to test significance of block differences of the same year, as well as tested for interaction with density. (Weed-free yield was excluded from these analyses, as percent yield loss for this treatment equaled zero.) If significant density-dependant effects were observed for each weight of grade, nonlinear regression analyses were performed on means. Tomato yield as a function of weed density was described through regression to fit a hyperbolic model of the form suggested by Cousens (1985):

$$Y=1*D/(1+(I*D/A)) \qquad [1]$$

where Y is percent yield loss, I is the percent yield loss as density approaches 0, D is weed density per planting hole, and A is the maximum or asymptotic percent yield loss. Data for straight yield and value (based on weekly price averages for the weeks harvested for large, extra large, and jumbo [NCDA 2004]) were subjected to ANOVA, and differences between means for fruit number and weight were compared by Fisher's protected least significant difference (LSD) test.

Results and Discussion

Yield loss (%) for weight of cull, three, medium, large, or extra large grade fruit was not affected by eastern black nightshade density (data not shown). Likewise, marketable, total, or sum of large, extra large and jumbo grades, was not affected by eastern black nightshade density (data not shown). However, significant density-dependent effects were observed for weight of jumbo (premium) grade fruits (P=0.0837). Year interaction was not significant so data were averaged over years, with densities 4 and 5 based on one year's data only. Regression analyses indicated a nonlinear jumbo grade tomato yield response over eastern black nightshade densities of 0 to 5 plants per hole (Equation 1, Figure 1). For jumbo grade fruit, the yield loss caused by each additional weed per hole is approximately 6.0% (Figure 1). The estimate of parameter A was 84% yield loss (Figure 1). The high standard error (55) for the estimate of parameter I (116) indicates high variability in the relationship between jumbo grade yield loss at eastern black nightshade densities between 0 and 1 eastern black nightshade per hole. Evaluation of densities between 0 and 1, for example 1 weed every three holes, would be useful for defining with better precision the percent yield loss as weed density approaches 0. This finding suggests that lower densities below one may need further evaluation for prediction of percent jumbo grade yield loss. However, it could be postulated that weed densities of less than one per hole are unlikely if a seed reserve is ample and water is plentiful, such as is customary in plasticulture with watering twice per week.

Mean comparison of yields showed no interaction between year and treatment, so data were combined over years, with densities 4 and 5 based on one year's data only, as above. Number and weight of extra large, jumbo, marketable, and total fruit categories of tomato showed a reduction by 1, 2, 3, 4, and 5 eastern black nightshade per hole, relative to the weed-free control. However, no differences in the densities across 1 to 5 were observed for each category (Tables 1 and 2). This analysis confers with the above percent yield loss analysis as affected by eastern black nightshade density that found no significant differences (except jumbo grade) for densities above zero. Mean number and weight of cull, medium, and large grades did not differ by any density (data not shown). These findings suggest that eastern black nightshade reduces quality since the larger grades (extra large, jumbo), marketable, and total yields are affected by the weed, but the smaller grades (medium, and large) and culls are not.

Number and weight of three-grade fruit for tomato with 4 weeds per hole differed from 0, 1, and 2; and 0 and 1 weed per hole, respectively, but is likely due to chance variability, since number and weight of those with 5 weeds per hole are slightly higher, and since threes are not limited to any size grade, but are judged by defects (Tables 1 and 2).

Some reports have suggested that weed biomass per unit area is an excellent predictor of crop biomass (Weaver and Tan 1983) or that weed biomass per unit area is more strongly correlated with tomato crop yield than weed density (Weaver 1979). It would be possible therefore, that biomass of one eastern black nightshade growing within the same hole with tomato could have equal biomass as several weeds growing within the same planting hole, thereby affecting number and weight of extra large, marketable, and total yield the same. Furthermore, another study found that when weeds were allowed to emerge for 21 d in transplanted tomatoes, then counted and thinned to densities of 0 to 100 % of their original density, the surviving 5% weeds of those plots with 95% weeds removed, grew vigorously and produced total weed weights equal to those of non-weeded plots (Friesen 1979). Therefore, 95% weed control was insufficient for avoidance of yield reduction, and weed vegetative growth and tomato yield reduction was the same regardless of weed density (Friesen 1979).

Value data were analyzed separately for each year. Values of large and extra large separately were not affected by eastern black nightshade density (data not shown). Value of jumbo fruit (Table 3) and the value of the sum of large, extra large, and jumbo grade (Table 4) varied by the densities tested. Gross income for the sum of large, extra large and jumbo grades ranged from \$17,755 to \$29,628 ha^{-1} with eastern black nightshade density ranging from 3 to 0 weeds per hole in 2003, and from \$16,413 to \$31,953 ha^{-1} for 5 to 0 weeds per hole in 2004 (Table 4). Gross income for jumbo grade ranged from \$1823 to \$9499 ha^{-1} with eastern black nightshade density ranging from 3 to 0 weeds per hole in 2003, and from \$2582 to \$9515 ha^{-1} for 5 to 0 weeds per hole in 2004 (Table 3). Given the present cost of eastern black nightshade control of \$430.00 ha^{-1} (D. W. Monks, personal communication), an average weed-free yield potential over both years of 11,697 kg ha^{-1} for jumbo grade and average value over both years of \$0.81 per kg for jumbo grade, the amount of yield loss required to offset the cost of control is 4.5% for jumbo. Solving equation 1 for D, given Y = 4.5, gives an economic threshold of 0.04 weed per planting hole (one weed per 11.25 m of row with 45 cm crop spacing) for jumbo grade.

In a study of palmer amaranth interference (*Amaranthus palmeri*) in transplanted plasticulture tomato, two palmer amaranth densities, one and three weeds per hole, were tested. No differences were found in tomato yield or quality due to a density effect (Garvey 1999). Therefore it can be postulated that another broadleaf may have similar effect at low densities in plasticulture tomato. This study shows 1 to 5 eastern black nightshade per planting hole reduce yield similarly from the weed-free check for extra large, marketable and total tomato yields, but the weight of the premium jumbo fruit showed asymptotic yield loss of 84% of weed-free yield. Further research is needed to determine the resources for which the plants are competing, and whether the lack of differential effect for 1 to 5 nightshade per hole is due to ample drip irrigation and fertility of a plasticulture system versus a bare ground system.

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Sources of Materials

[4] Dillen Products, Vacuum Forming Division, Middlefield, OH 44062.

[5] Metro-Mix 360 organic potting mix, Scotts-Sierra Horticultural Products Co., 1411 Scottslawn Road Marysville, OH 43040.

[6] ‘Amelia’ tomato, Harris Moran Seed Company, P.O. Box 4938, Modesto, CA 95352.

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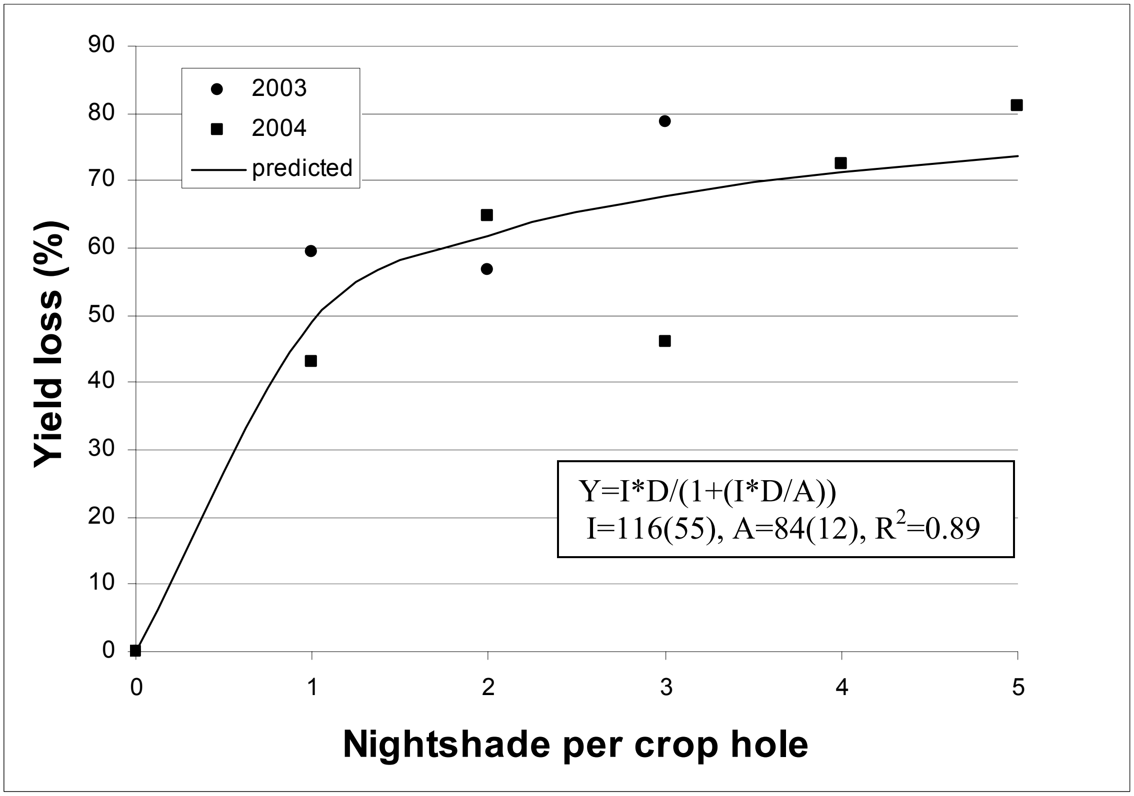

Figure 1. Effect of eastern black nightshade density on percent loss of jumbo grade fruit. Parameter estimates for A and I are followed in parentheses by their standard errors. Y is percent yield loss, I is percent yield loss as density approaches 0, D is weed density per planting hole, and A is asymptotic percent yield loss.

Table 1. Eastern black nightshade density effects on tomato fruit number per hectare combined across 2003 and 2004 [a].

Eastern black nightshade density	Fruit grade			Fruit group	
	Threes	Extra large	Jumbo	Marketable[b]	Total[c]
Weeds per hole	fruit number / ha				
0	18879 a	44863 a	28420 a	202391 a	224924 a
1	10353 b	29029 b	13601 b	157934 b	178437 b
2	8323 b	25172 b	10962 b	145957 b	165242 b
3	6495 bc	30247 b	9947 b	158137 b	174885 b
4[d]	1015 c	30450 b	10488 b	138717 b	155972 b
5[d]	4737 bc	31803 ab	8797 b	134657 b	152927 b
LSD(.05)	7306	14219	6636	33962	37548

[a]Means followed by the same letter are not significantly different according to Fisher's Protected LSD at P = 0.05.

[b]Marketable yield equals the sum of threes, medium, large, extra large, and jumbo fruit.

[c]Total yield equals the sum of culls, threes, medium, large, extra large, and jumbo fruit.

[d]Data for these densities are based on one year's (2004) data only.

Table 2. Eastern black nightshade density effects on tomato fruit weight per hectare combined across 2003 and 2004[a].

Eastern black nightshade density	Fruit grade			Fruit group	
	Threes	Extra large	Jumbo	Marketable[b]	Total[c]
Weeds per hole	kg / ha				
0	5518 a	13901 a	11577 a	54264 a	59201 a
1	2556 b	8749 b	5168 b	37862 b	41694 b
2	1969 bc	7686 b	4161 b	33690 b	36536 b
3	1687 bc	8975 b	3741 b	36804 b	40391 b
4[d]	305 c	9318 b	3925 b	32656 b	35627 b
5[d]	1272 bc	9419 b	3207 b	31654 b	34950 b
LSD(.05)	1725	4291	3203	9354	10114

[a]Means followed by the same letter are not significantly different according to Fisher's Protected LSD at P = 0.05.

[b]Marketable yield equals the sum of threes, medium, large, extra large, and jumbo fruit.

[c]Total yield equals the sum of culls, threes, medium, large, extra large, and jumbo fruit.

[d]Data for these densities are based on one year's (2004) data only.

Table 3. Effect of eastern black nightshade density on jumbo grade tomato yield and value[a], Fletcher, NC, 2003 and 2004.

Eastern black nightshade density	Tomato yield		Value	
	2003	2004	2003	2004
Weeds per hole	kg/ha		$/ha	
0	11101	12292	9499	9515
1	4412	6303	3872	4884
2	4452	3725	3981	2829
3	2125	6166	1823	5028
4	-	3925	-	3111
5	-	3207	-	2582
LSD (.05) [b]	3296	4115	2897	3091

[a]Value is based upon U. S. Combination, generally 80% U.S. no.1 quality or better, 2004 season, weekly averages for weeks harvested (price for jumbo=$1.00, 0.77, 0.68, 0.77/kg). (NCDA 2004).

[b]Means differing by at least this amount are different according to Fisher's Protected LSD at P = 0.05.

Table 4. Effect of eastern black nightshade density on sum of large, extra large, and jumbo grade tomato yield and value[a], Fletcher, NC, 2003 and 2004[b].

Eastern black nightshade density	Tomato yield		Value	
	2003	2004	2003	2004
Weeds per hole	kg/ha		$/ha	
0	41571	46568	29628	31953
1	28427	29760	21115	19949
2	25294	24695	18886	16528
3	25578	32597	17755	21761
4	-	25639	-	17155
5	-	25064	-	16413
LSD(.05)[b]	6754	15120	5054	10093

[a]Value is based upon U. S. Combination, generally 80% U.S. no.1 quality or better, 2004 season, weekly averages for weeks harvested (price for large= $0.87, 0.59, 0.50, 0.64/kg; price for extra large = $0.92, 0.70, 0.59, 0.70/kg; price for jumbo=$1.00, 0.77, 0.68, 0.77/kg). (NCDA 2004).

[b]Means differing by at least this amount are different according to Fisher's Protected LSD at P = 0.05.

Eastern black nightshade (*Solanum ptycanthum* Dun.) reproductive potential and effect on tomato yield loss in transplanted plasticulture tomato (*Lycopersicon esculentum*)[1]

JULIANA K. BUCKELEW and DAVID W. MONKS[2]

Abstract: Field experiments were conducted to determine the effect of eastern black nightshade on tomato yield loss growing in-row with plasticulture tomato, as well as eastern black nightshade berry production and seed viability. Eastern black nightshade was transplanted at 1, 2, 3, 4, 5, 6, and 12 weeks after tomato planting (WAP) and remained until tomato harvest, or was established at tomato planting and removed at 2, 3, 4, 5, 6, 8, and 12 WAP to determine the critical weed-free periods. Seed viability of medium and large berries was 7 to 100% and increased with length of establishment or removal time. Extra small and small berries had low viability of 0 to 8%. The critical weed-free period to avoid viable seed production was 3 to 6 WAP. No treatment differences in tomato yield were found in year 1. In year 2 at the first location, weight of three-grade fruit varied by establishment time. In year 2 at the second location, differences in the sum weight of extra large and jumbo grades occurred. The critical weed-free period to avoid greater than 20% yield loss for the sum weight of extra large and jumbo grades was 28 to 50 days after tomato transplanting, and was economically justified based on 2004 tomato prices during weeks harvested.

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[1] Received for publication date and in revised form date.

[2] Graduate research assistant and professor, Department of Horticultural Science, North Carolina State University, Raleigh, NC 27695.

Nomenclature: Eastern black nightshade, *Solanum ptycanthum* (Dun.) #[3] SOLPT; tomato, *Lycopersicon esculentum.*

Additional index words: Competition, critical period, interference, models, weed-free period, viable seed production.

Introduction

Many North Carolina vegetable growers increase their market advantage by using plasticulture. The plasticulture system combines raised beds, plastic mulch, drip fertigation, and methyl bromide fumigation to produce increased rate of basal branch appearance, total plant growth, early flowering, and early yield of tomato (Maynard and Hochmuth 1997; Wien and Minotti 1987 and 1988). Black plastic mulch also suppresses most weed seed germination and growth (Teasdale and Colacicco 1985). However, one disadvantage of this production system is the competition caused by weed seeds not killed during fumigation or that originate from row middles that germinate and establish in the 9 to 10 cm diameter openings in the plastic next to tomato transplants (Monks et al. 1997). Close proximity of weed and crop can increase weed/crop interference (Monks and Oliver 1988; Pike et al. 1990) and likely creates a different interference scenario in plasticulture compared to bare ground tomatoes, for which most weed/crop interference research in transplanted tomatoes has been done. The phase-out of methyl bromide in 2005 (EPA 1990) will likely increase the probability of weed seed germination and establishment within planting beds, and increase the importance of this problem.

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

Solanaceous weeds like eastern black nightshade (*Solanum ptycanthum* Dun.) are closely related to tomato, so control of eastern black nightshade by herbicides is difficult without injuring tomato (Gorski and Wertz 1987). Nightshade has been shown to reduce yields in bare ground tomato production (McGiffen et al. 1992; Weaver et. al. 1987). Eastern black nightshade is also one of the ten most troublesome weeds of soybean in North Carolina (Webster 2001). It is adapted to shaded environments such as under a crop canopy (Stoller and Myers 1989). Eastern black nightshade is an annual that grows up to 1 m high and is common throughout North America east of the Rocky Mountains (Bassett and Munro 1985; Ogg and Rogers 1989).

Time of planting and crop interference can impact nightshade growth and reproduction. Time of flowering and amount of berry production by black nightshade without crop interference varied by emergence date when field sown in March to October in California (Keeley and Thullen 1983). Quakenbush and Andersen (1984) found that eastern black nightshade berries first contained viable seeds 4 to 5 wks after flower opening. Nightshade seedlings cannot become established into soybeans after the canopy has closed (Quakenbush and Andersen 1984). Knowledge of viable seed production considering planting time and competition with tomato grown in the plasticulture production system can be useful for prevention of future weed infestations for the tomato grower.

The critical period for broadleaf weed competition with tomatoes is 30 to 40 days after tomato transplanting (DAT) when tomato flowering and fruit set first occur (Perez and Masiunas 1990; Weaver and Tan 1983). Weaver and Tan (1983) found that from approximately 28 to 35 DAT, a single but thorough weed removal will prevent losses in tomato dry weight, stomatal conductance, and fruit number. Other studies in bare ground transplanted tomato have found the critical period of interference for broadleaves to be 28 to 35 days in Jordan (Qasem 1992), 24 to 36 DAT in Canada (Friesen 1979), and 5 to 9 weeks after seeding in seeded tomatoes in Canada (Weaver 1984). However, no reports specific for eastern black nightshade interference could be found for plasticulture-grown tomatoes.

The objectives of this research were two fold: to determine eastern black nightshade berry production and seed formation in a plasticulture system, and to determine tomato yield loss and critical weed-free period for eastern black nightshade when tomato was grown in a plasticulture production system.

Materials and Methods

Field experiments were conducted in 2003 and 2004. In 2003, studies were conducted at the Mountain Horticultural Crops Research Station in Fletcher, NC (82.56 degrees N, 35.43 degrees W, elevation 631 m). Soil was Bradson gravelly loam (clayey, oxidic, mesic Typic Hapludults) with pH 6.2 and humic matter 0.56%. Fertilizer was broadcast incorporated with 83, 214, and 138 kg N, P_20_5, K_2O ha^{-1}, respectively, before soil bedding and plastic mulch application. In 2004, the tomato yield study was conducted at the Horticultural Crops Research Station in Clinton, NC (35.02 degrees N, 78.28 degrees W, elevation 48 m). Soil was Norfolk loamy sand (fine loamy, kaolinitic, thermic Typic Kandiudults) with pH 6.1 and humic matter 0.66%. Fertilizer was broadcast incorporated with 56, 56, and 112 kg N, P_20_5, K_2O ha^{-1}, respectively, before soil bedding and plastic mulch application. In 2004, studies were conducted at the Mountain Horticultural Crops Research Station. Soil was Comus fine sandy loam (coarse-loamy, mixed, mesic

Fluventic Dystrochrepts) with pH 6.2 and humic matter 1.31%. Fertilizer was broadcast incorporated with 84, 316, and 185 kg N, P_20_5, K_2O ha^{-1}, respectively, before soil bedding and plastic mulch application. Dolomitic lime was also incorporated at 2240 kg ha^{-1}. In all studies, methyl bromide was applied under the black plastic, and weekly fertigation schedules and plasticulture practices were followed as recommended by NC Cooperative Extension Service (Sanders et al. 1996).

Tomato transplants approximately 20 cm tall with 4 to 5 true leaves were hand planted June 4, 2003 and June 14, 2004 at Fletcher, and May 7, 2004 at Clinton using a 6.5 cm diameter bulb planter to open the holes in the plastic. Within 24 h after tomato transplanting, eastern black nightshade seedlings with two true leaves were transplanted into the same planting hole as tomato. Eastern black nightshade transplants, sown approximately 18 d prior to planting using a 98 cell plug tray[4] containing potting media[5], were used to ensure uniformity. Other similar research has also used eastern black nightshade transplants (Croster and Masiunas 1998; McGiffen, et al. 1994; McGiffen and Masiunas 1992; McGiffen, Masiunas, and Hesketh 1992; McGiffen, Masiunas, and Huck 1992; Perez and Masiunas 1990). All weed seedlings were transplanted approximately 3 cm from the tomato. Eastern black nightshade seeds used in both years were collected from Vale, North Carolina in fall of 2002. A plant specimen from this experiment was deposited at the North Carolina State University Plant Herbarium for taxonomic reference.

Plots were single-row plantings of fresh market, determinate cultivar ‘Amelia’[6] tomato and eastern black nightshade plants. Plot size was 1.5 by 4.5 m. Row centers were 1.5 m apart; space between plants within the row was 45 cm. Of the ten plants per plot, the middle six were harvested and the outer two on each end were buffer plants. To avoid shading of neighboring plots, 91 cm were left between each plot within the row. Bed width was 70 cm at the base and 63 cm at the top. Height of the beds from base to ridge was approximately 16 cm. Row middles were maintained weed-free throughout the growing season by applying napropramide at 4.5 kg ha^{-1} after planting and paraquat at 0.6 kg ha^{-1} postemergence as needed. Weeds other than eastern black nightshade growing within the planting holes were controlled by hand removal.

Hand harvest began when approximately 5% of all fruit were at the physiological fruit stage of breaker, which was usually evident when a yellowish-tan star formed at the blossom end. Fruit stage at the subsequent harvests was breaker stage to red. The final harvest consisted of all fruit 5 cm in diameter and larger, regardless of color classification. All fruit were graded by hand and sized by machine according to United States standards for grades of fresh market tomato consisting of these grades: medium, large, extra-large, and jumbo (5 to 6.4, 6.4 to 7.3, 7.3 to 8.8, and greater than 8.8 cm in diameter, respectively) (Anonymous 1997). Three-grade fruits were of various sizes without serious damage or defects, but were not of first quality. Marketable fruit consisted of three, medium, large, extra large, and jumbo grades; total fruit consisted of these grades plus culls.

The experimental design was a randomized complete block design replicated four times. Data from plots with eastern black nightshade transplanted at 1, 2, 3, 4, 5, 6, and 12 weeks after tomato planting (WAP) and remaining until tomato harvest determined the minimum weed-free period after planting needed for maximum tomato yield. Data from plots with eastern black nightshade established at tomato planting and removed at 2, 3, 4, 5, 6, and 8 and 12 WAP determined the maximum period of nightshade competition after tomato planting that minimized yield loss (Table 1). The time between these two points in time is called the critical weed-free period (Zimdahl 1988). Weed removal at 12 WAP and weed establishment at 12 WAP are the weedy all season and weed-free treatments, respectively.

The average heights of crop and weed at time of weed removal were calculated from the plants of two randomly chosen planting holes per plot. Likewise, the average aboveground vegetative biomass of the weed at time of its removal was calculated from the same plants by cutting the stem at the soil surface and drying at 60 degrees C until weight was constant. Averages for final tomato plant height were calculated from the same two corresponding planting holes. Average heights and biomass for remaining weeds in establishment plots were calculated at final tomato harvest as well. Any berries greater or equal to 3 mm diameter were gathered from a berry-catching device or picked from the plant and graded by sieves into size fractions: extra small, small, medium, and large (3 to 5, 5 to 6.3, 6.3 to 9, and greater than 9 mm, respectively). Each grade was dried at 60 degrees C until weight was constant. Dry weight of berries for each grade was recorded. Seeds were counted in 10 randomly chosen berries of each grade and average seed number per berry calculated. From another randomly chosen planting hole in each plot, berries were harvested and graded into size fractions, then the seeds were separated from berries and their viabilities were tested by germinating on 2 pieces of filter paper moistened with 6 ml of water in plastic 9 cm diameter petri dishes at alternating 20 and 30 C, 10 and 14 hr photoperiod, under 3.8 $\mu mol\ s^{-1}\ m^{-2}$

phototsynthetically active radiation for two weeks. All nongerminated seeds were then stained with tetrazolium chloride to test for viability. Each group of seeds was placed into four petri dishes in 2003 and three in 2004, each dish containing 25 seeds. The average viability per treatment per grade was calculated by averaging the percent viable for the several dishes.

Eastern black nightshade seed viability percentages were transformed by calculating the arcsine of the square root to correct for homogeneity of variance, then a rich model including several possible explanatory variables was trimmed based on extra sum of squares (Rao 1998) tests (SAS 1999). Berry weight data were subjected to ANOVA, and means separated by Fisher's protected LSD. Tomato yield, value (based on weekly price averages for the weeks harvested for large, extra large, and jumbo [NCDA 2004]) and weed vegetative biomass data were subjected to ANOVA, with year nested within block to test significance of block differences of the same year. Value for large, extra large, and jumbo separately, as well as the sum of these grades in all possible combinations, was analyzed. When linear or quadratic contrasts were significant at the 0.05 level or below for removal and establishment treatments, means were regressed to describe trends. Weed biomass for establishment treatments as a function of WAP was described through regression to fit an exponential model of the form:

$$Y=Be^{-K*WAP} \qquad [1]$$

where Y is biomass, B and K are constants, e is the base of natural logarithms, B is the value of Y when WAP (weeks after tomato transplanting that the weed is established) = 0, and K is the rate at which Y decreases towards zero as WAP becomes large (Cousens et al. 1987). Tomato yield and value for establishment treatments as a function of WAP was described through regression to fit a hyperbolic model of the form:

$$Y=I*WAP/(1+(I*WAP/A)) \qquad [2]$$

where Y is yield, I and A are constants, and WAP is weeks after tomato transplanting that the weed is established (Draper and Smith 1981).

Results and Discussion

Eastern Black Nightshade Growth and Reproduction. If eastern black nightshade establishes at time of tomato planting and is allowed to grow throughout the production season with tomato, it grows steadily and shows a linear increase in biomass production (Figure 1). As establishment is delayed with WAP, biomass production is exponentially less (Equation 1; Figure 1). Eastern black nightshade started to overtop the tomato if it was established at 1 WAP, or if it was established with the crop and removed at six WAP or after (data not shown). As mentioned previously, Bassett and Munro (1984) and Ogg and Rogers (1989) reported eastern black nightshade grows up to 1 m tall, but eastern black nightshade present all season averaged 1.38 m tall at Fletcher in 2003 and 2004, and 0.94 m at Clinton in 2004 (data not shown). The difference in height of eastern black nightshade at Fletcher from the botanical description was likely a benefit from the added support of tomato staking and the plasticulture production system compared to a native or bare ground cropping environment. At Clinton, plants probably remained shorter due to warmer and less cloudy conditions than Fletcher.

Regression analyses indicated percent viability to be a function of berry grade, time of weed establishment or removal, and an interaction between the two ($R^2 = 0.87$) (Figures 2a and 2b). Data are presented as the predicted means of subpopulations. Delay of eastern black nightshade until after 3 weeks after tomato transplanting or control by 6 weeks after transplanting needs to occur to prevent all viable seed production (Figures 2a and 2b). Extra small berries were viable (0.3% or less) for removal treatments only (Figures 2a and 2b). Viability of seed obtained from medium and large berries (7 to 93% and 99 to 100%, respectively) was higher than seed obtained from extra small and small berries (0 to 0.3% and 0 to 8%, respectively) (Figures 2a and 2b). This finding suggests a higher importance of medium and large berries in consideration of additions to the soil seed bank since viability of seed is much greater than seed obtained from smaller berries. For medium and large berries, percent viability increases with the length of growth period (Figures 2a and 2b). Specifically, it decreases as establishment is delayed, and increases as removal is delayed (Figures 2a and 2b). Similar results for eastern black nightshade were reported by Thomson and Witt (1987) and Stoller and Myers (1989), the latter finding that seed maturation was a function of time after anthesis, while viable seeds approached 100% in 18 to 22 days after anthesis. Eastern black nightshade planted at time of tomato planting began flowering at approximately 32 days after planting at Clinton and Fletcher. These findings mean that a critical period of weed removal exists from 3 to 6 weeks after transplanting that should be observed to minimize viable seed production, and that weed growth commenced earlier than 3 weeks, and controlled later than 6 weeks, will produce increasing numbers of viable seeds.

In terms of weed biomass, the critical period for viable seed production from 3 to 6 WAP corresponds to weeds that were established at 3 WAP or before (9 to 12 wk growth period) and were 5.5 grams dry biomass or greater, and those weeds that were removed at 6 WAP or after (6 to 12 wk growth period) and were 29.5 g dry biomass or greater

(Figure 1). The former was smaller despite having a longer growth period, and the latter was larger despite a shorter growth period. The difference in biomass was likely due to a difference in shading since the smaller plant was shaded all season and the larger was able to overtop the tomato. Stoller and Myers (1989) reported that eastern black nightshade produced 38 g and 1 g biomass in full sun and 94% shading, respectively, in an 11 wk growth period. Past 3 WAP, weeds that established in the tomato stayed below 5.5 grams dry biomass, reflecting the difficulty for the weeds to become established after the tomato has established. Eastern black nightshade shoot dry weight ranged from 84 g per plant when able to overtop the tomato and reach full sunlight at a 12 wk growth period (weedy all season) to 9 g plant^{-1} under shade at a 9 wk growth period (establishment at 3 WAP), also suggesting that biomass is largely due to shade level after accounting for growth period.

Medium and large berries contained an average of 101 and 105 seeds per berry, and weighed 0.03 and 0.09 g dry weight per berry, respectively. The first berries were produced by 6 WAP (Figure 3a), which is similar to other reports (Perez and Masiunas 1990, Ogg et al. 1981, and Quakenbush and Andersen 1984). Eastern black nightshade present all season produced the largest amount of medium and large berries, which was 1231 medium berries (124,350 seeds) and 127 large berries (13,348 seeds) per plant, respectively, followed by those that were established 1 WAP , which was 302 medium berries (30,501 seeds) and 25 large berries (2,627 seeds) per plant, respectively (Figures 4 and 5). Similar reports in which tomato was produced in a bare ground production system have found nightshade planted before week 3 and growing until harvest had maximum berry production (Perez and Masiunas 1990). Quakenbush and Andersen

(1984) found that eastern black nightshade established into soybeans through the growing season produced progressively fewer berries, similar to these findings in plasticulture tomato (Figure 3b). These results show that nightshade can produce highly viable seeds if established at 3 WAP or before, or if not controlled by 6 WAP, and berry production and seed viability increase outside of this time period.

Yield. At Fletcher in 2003, no significant treatment differences, tested by linear and quadratic contrasts, were observed for the tomato grades. Tomato plants were infected with early blight (*Alternaria solani*) and botrytis cane blight (*Botrytis cinerea*) causing premature defoliation and wilt (Plant Disease and Insect Clinic 2003). Early blight can cause up to 50% yield losses (North Carolina State University Cooperative Extension Service 1999) and likely confounded any treatment effects. At Fletcher in 2004, there was a hyperbolic trend for tomato grade weight of threes (Figure 4). However, no other significant trends were observed for the other tomato grades. The field location was flooded much of the season and the soil stayed saturated. A treatment difference in weight of threes might have been a quality issue due to flooding, and be more of a reflection of total weight. Tomato fruit yield at 80% or greater of the predicted weed-free yield (7376 kg ha^{-1}) for weight of threes would require weeds to be controlled at 9 days after tomato transplanting. The choice of 80% is an arbitrary measurement of yield loss, and the range of percent yield loss can vary by the risk that the crop consultant or producer is willing to take (Knezevic et al. 2002).

At Clinton in 2004, time of establishment and time of removal of nightshade affected tomato yield for the sum weight of jumbo and extra large grades (Figure 5), and for total weight (Figure 6). For both categories, the tomato yield for those plants with season long nightshade interference was higher than the yield of those plants with nightshade interference from 1 WAP to tomato harvest, which could be due to injury at time of establishment to the young tomato. Both categories of yield followed a hyperbolic treatment effect (Equation 2) for establishment treatments, and a linear treatment effect for removal treatments (Figure 5 and 6). Yield at 80% or greater of the predicted weed-free (27,349 kg ha^{-1}) for weight of jumbo and extra large grades is minimally 21,879 kg ha^{-1}, and corresponds to a critical weed-free period (to prevent 20% yield loss) of 28 to 50 d after tomato transplanting (Figure 5). Similarly, Perez and Masiunas (1990) found that eastern black nightshade greatly reduced tomato yield when not controlled by 6 wks after transplanting tomato. This period coincides with the full bloom stage and fruit set for tomato (Friesen 1979; Perez and Masiunas 1990). Shading of tomato has been shown to decrease yield (McGiffen et al. 1992), and light intensity during anthesis and early fruit set determine the number of tomatoes per plant (McAvoy and Janes 1989; McGiffen et al. 1992). In Clinton and Fletcher, tomato flowering began approximately 28 and 18 days after transplanting, respectively, and early fruit set (when oldest tomatoes were 4 to 7 cm in diameter) was approximately 42 and 46 days after transplanting, respectively. Removal of eastern black nightshade during the time period of 28 to 50 days after transplanting would prevent tomato shading during this critical time.

Given the present cost of eastern black nightshade control (by hand removal) of \$430.00 ha^{-1} (D. W. Monks, personal communication), a predicted weed-free tomato yield potential of 27,349 kg ha^{-1} for the sum of extra large and jumbo grades, and an average value of \$0.59 kg^{-1} (NCDA 2004) for extra large and jumbo grades during the weeks harvested, the amount of yield loss required to offset the cost of control is 2.7%.

The weed-free potential minus a 2.7% yield loss equals 26,611 kg ha^{-1}. Damage due to eastern black nightshade interference would need to be at least 2.7% to justify the cost of control. Data for the value of gross income per ha for extra large and jumbo, the premium grades, as affected by eastern black nightshade establishment and removal times, are presented in Figure 7. A critical weed-free period of 28 to 50 days after tomato transplant would be economically justified for the sum of extra large and jumbo grades.

For extra large grade value alone, linear contrasts were significant for establishment treatments, and quadratic contrasts were significant for removal treatments (data not shown). For sum of the value of large, extra large, and jumbo grades, linear contrasts were significant for establishment and removal treatments (data not shown). Means were not regressed since yield contrasts were not significant, as mentioned previously. Value for Fletcher yields for both 2003 and 2004 did not have contrast significance (data not shown).

At Clinton, tomato yield at 80% of the predicted weed-free yield (57,326 kg ha^{-1}) for total weight was 45,861 kg ha^{-1} (Figure 6), which corresponds to 4 to 87 d after tomato transplanting for the critical weed-free period. The period of control for total weight would need to be evaluated for economic feasibility, since culls and threes comprise this category of yield as well, and 87 d extends to the end of the production season.

Garvey (1999) found a critical period of 30 to 35 days after tomato transplant for any yield loss caused by palmer amaranth in plasticulture tomato. In this study, eastern black nightshade needs to be controlled for a longer period of time, until 50 days, and allows a 20% yield loss. He found that palmer amaranth overtopped the tomato at 6 WAP (Garvey 1999), similar to eastern black nightshade results from this study. However, this study suggests that eastern black nightshade has a greater ability than palmer amaranth to reduce yield if control is delayed.

The longer period (50 d) required to control nightshade after tomato transplanting than other periods (35, 35, 36, and 40 d) mentioned above for bare ground tomato suggests that the weed is more competitive with tomato when grown on plasticulture. This may be due to the ready supply of water and nutrients supplied through drip irrigation which the weed can utilize, and/or elimination of competition with other weeds. Further research is needed to decipher for what resources the weed and tomato are competing.

The critical period of weed interference should be treated as a tool in IPM. Where eastern black nightshade is a problematic weed of tomato, 28 to 50 days can serve as a guide for the critical period of interference. This time period would need to begin one wk earlier to eliminate the production of highly viable seed production, since a weed-free period of 3 to 6 WAP would reduce highly viable seed production of medium and large berries, thereby reducing future infestations of eastern black nightshade.

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Sources of Materials

[4] Dillen Products, Vacuum Forming Division, Middlefield, OH 44062.

[5] Metro-Mix 360 organic potting mix, Scotts-Sierra Horticultural Products Co., 1411 Scottslawn Road Marysville, OH 43040.

[6] 'Amelia' tomato, Harris Moran Seed Company, P.O. Box 4938, Modesto, CA 95352.

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Table 1. Eastern black nightshade establishment (EST) and removal (REM) treatments in 2003 and 2004.

	WAP[a]								
	1	2	3	4	5	6	7	8	12
EST	X	X	X	X	X	X			X
REM		X	X	X	X	X		X	X

[a]WAP = weeks after tomato planting.

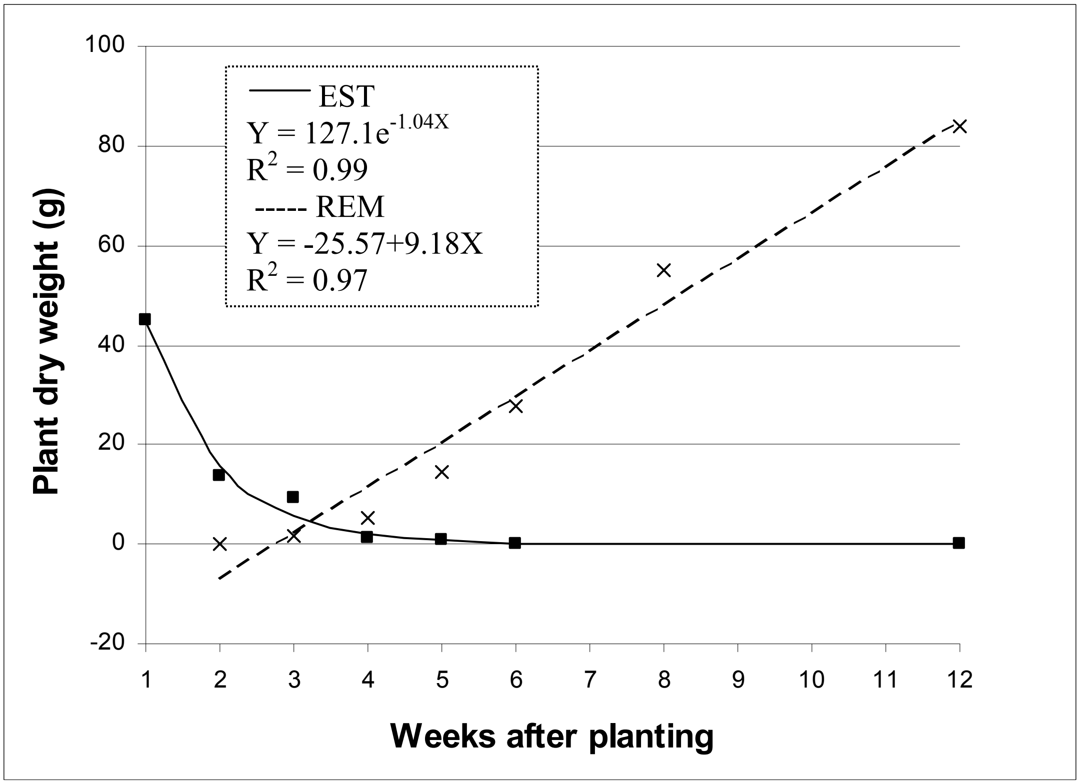

Figure 1. Effect of eastern black nightshade establishment (EST) and removal (REM) treatments on weed biomass. Data combined for 2003 and 2004. Means for EST and REM are represented by (▪) and (x), respectively.

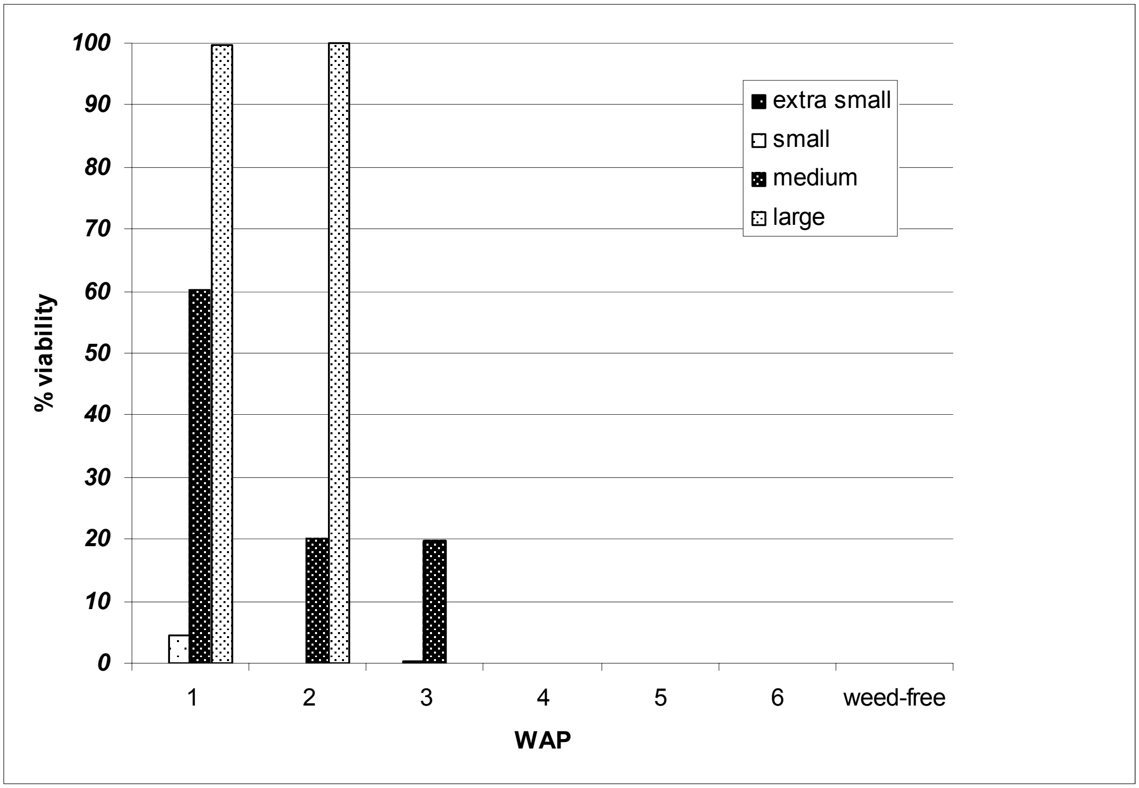

Figure 2a. Effect of eastern black nightshade established at various weeks after tomato transplanting (WAP) and berry size on end-of-season seed viability. Data combined over 2003 and 2004. The percent viability values are the predicted means of each subpopulation as determined from the multiple linear regression procedure and are back-transformed for presentation. The regression equation is $\sin^{-1} \sqrt{}$ (% seed viability) = 1.55 + GRADE + WAP + GRADE * WAP. (R^2 = .87).

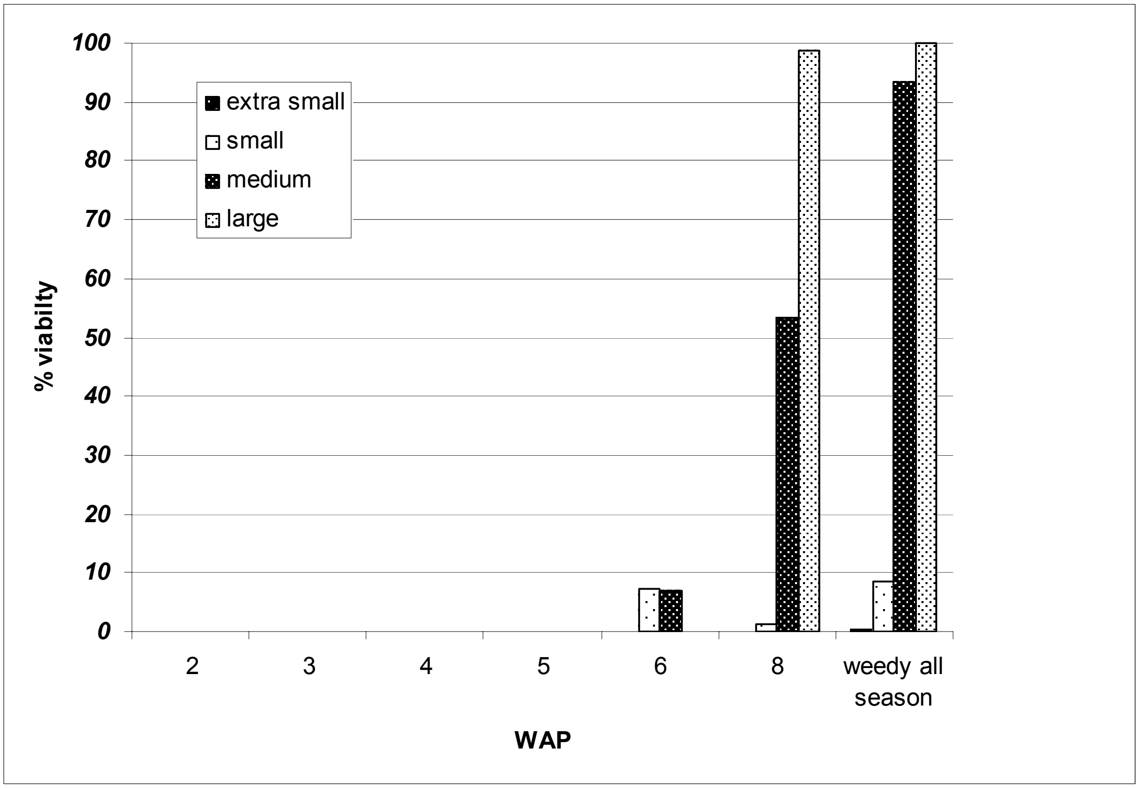

Figure 2b. Effect of eastern black nightshade removed at various weeks after tomato transplanting (WAP) and berry size on end-of-season seed viability. Data combined over 2003 and 2004. The percent viability values are the predicted means of each subpopulation as determined from the multiple linear regression procedure and are back-transformed for presentation. The regression equation is $\sin^{-1}\sqrt{(\%\ \text{seed viability})} = 1.55 + \text{GRADE} + \text{WAP} + \text{GRADE} * \text{WAP}$. ($R^2 = .87$).

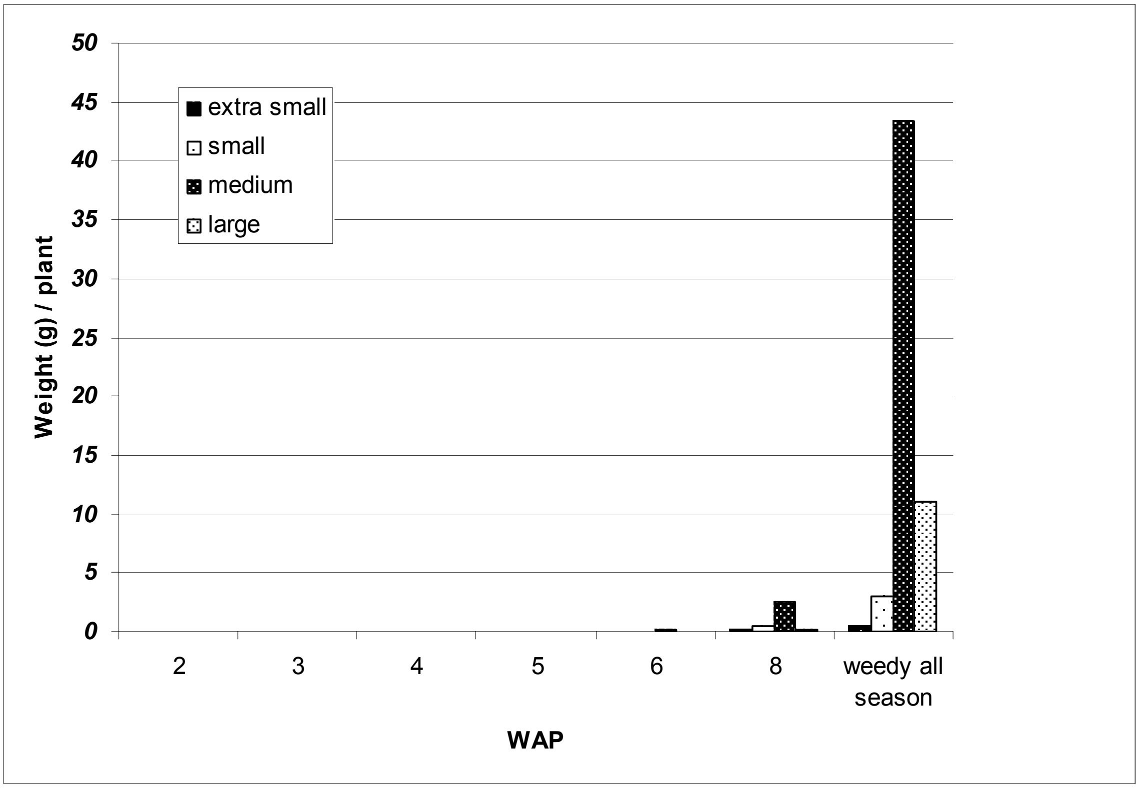

Figure 3a. Effect of eastern black nightshade removed at various weeks after tomato transplanting (WAP) on end-of-season berry weight. Data combined over 2003 and 2004. Means are significantly different according to Fisher's protected LSD (0.05) if they differ by 0.06, 0.56, 6.09, and 2.29 for extra small, small, medium, and large berries, respectively.

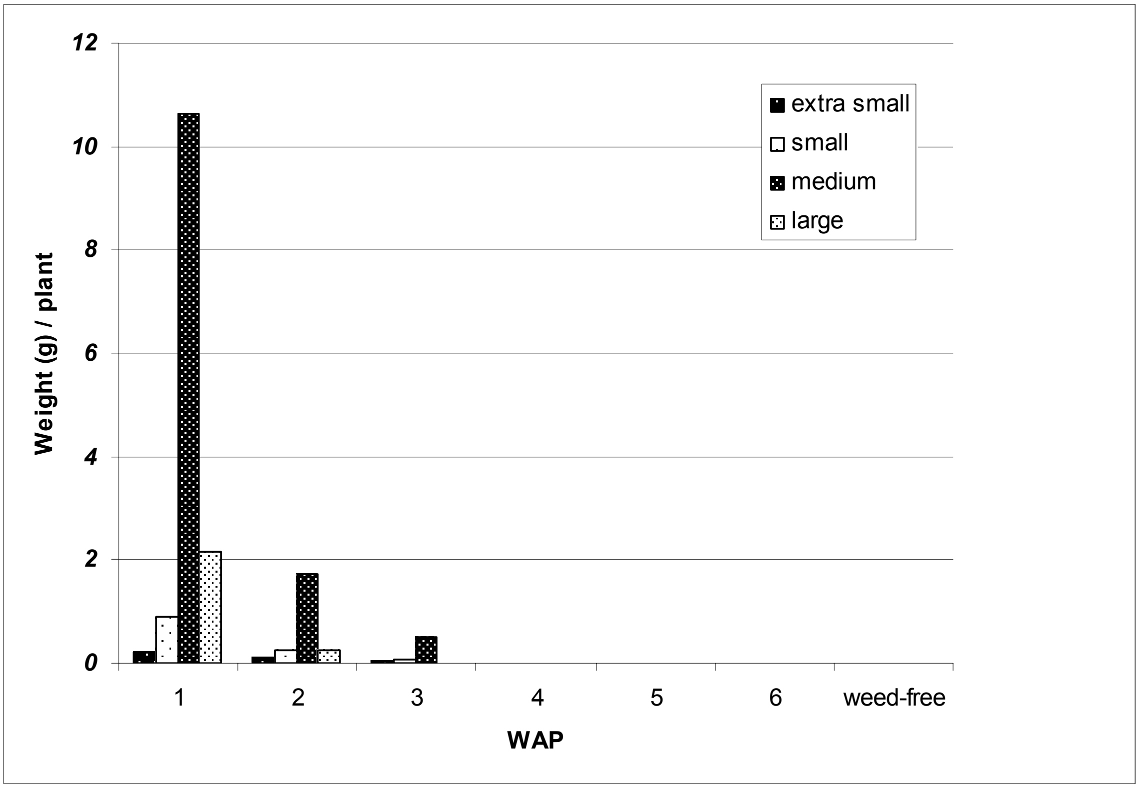

Figure 3b. Effect of eastern black nightshade established at various weeks after tomato transplanting (WAP) on end-of-season berry weight. Data combined over 2003 and 2004. Means are significantly different according to Fisher's protected LSD (0.05) if they differ by 0.05, 0.18, 1.64, and 0.53 for extra small, small, medium, and large berries, respectively.

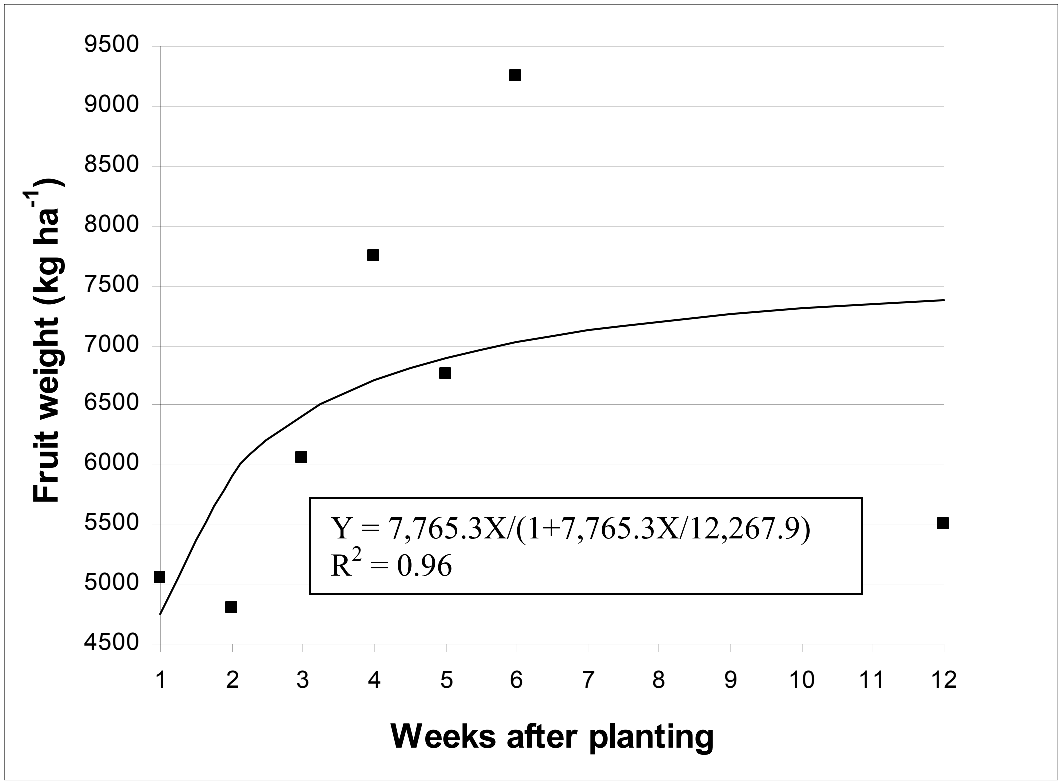

Figure 4. Effect of eastern black nightshade establishment treatments on weight of three grade fruit at Fletcher in 2004. Means are represented by (▪).

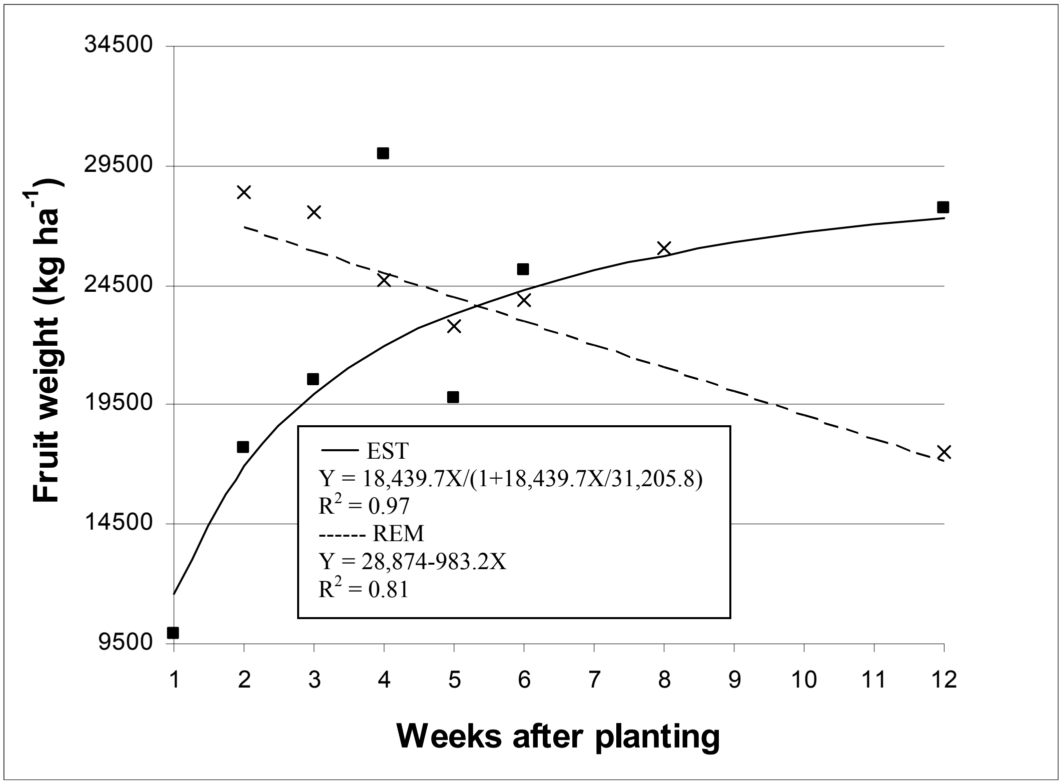

Figure 5. Effect of eastern black nightshade establishment (EST) and removal (REM) treatments on weight of the sum of jumbo and extra large grade fruit at Clinton in 2004. Means for EST and REM are represented by (▪) and (x), respectively.

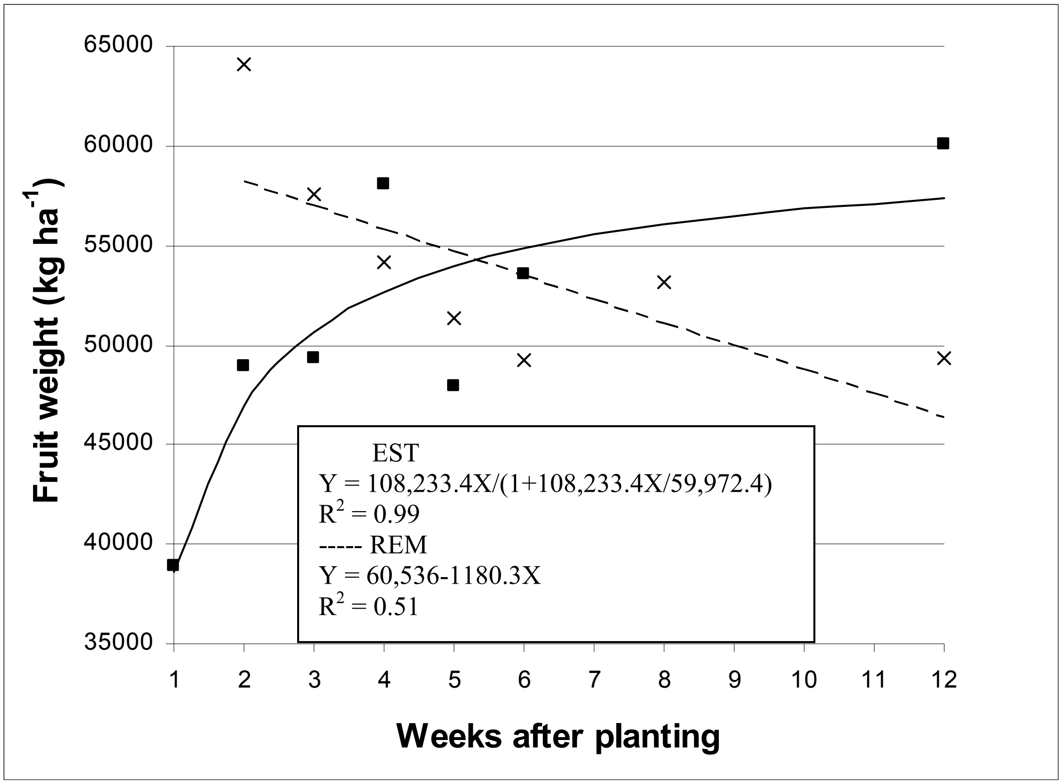

Figure 6. Effect of eastern black nightshade establishment (EST) and removal (REM) treatments on total (including culls) fruit weight at Clinton in 2004. Means for EST and REM are represented by (▪) and (x), respectively.

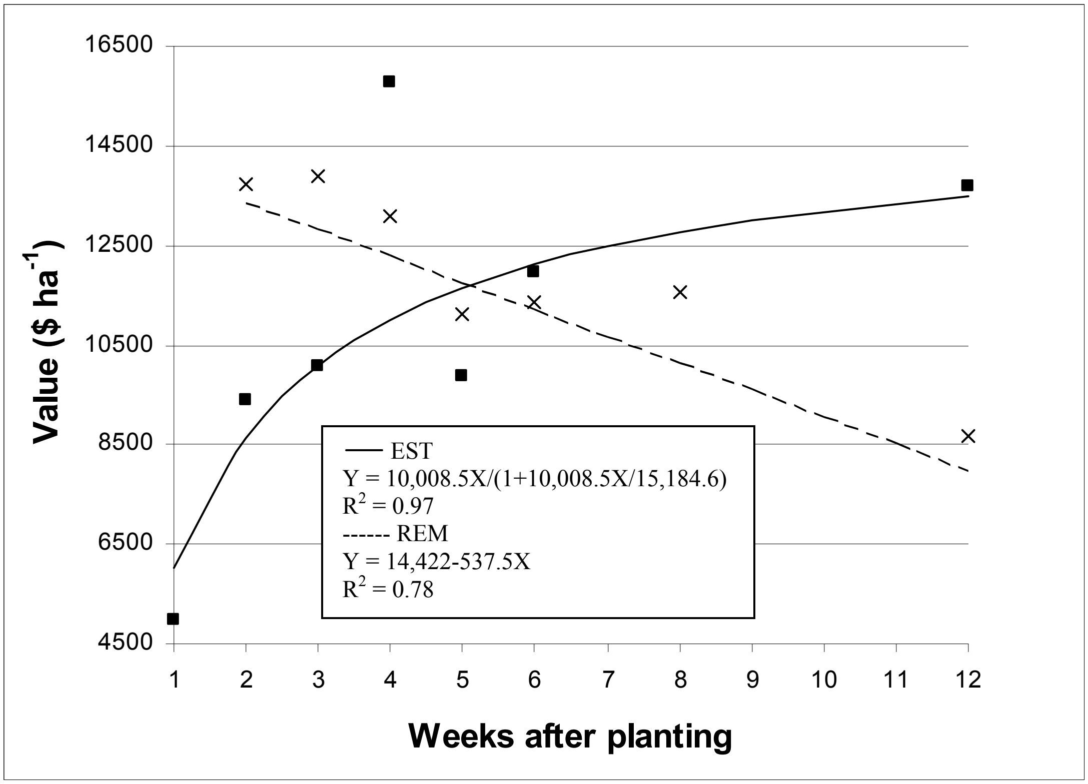

Figure 7. Effect of eastern black nightshade establishment (EST) and removal (REM) treatments on the value of the sum of jumbo and extra large grade fruit at Clinton in 2004. Means for EST and REM are represented by (▪) and (x), respectively.

Post-directed Herbicide Evaluations in Tomato (*Lycopersicon esculentum*) in a Plasticulture System[1]

JULIANA K. BUCKELEW and DAVID W. MONKS

Abstract: Field experiments were conducted in 2003 to identify those herbicides that were safe to tomato postemergence directed in plasticulture tomato and in 2004 to determine the effect of these herbicides postdirected at various rates on tomato injury and weed suppression. Apple of Peru, eastern black nightshade, fall panicum, goosegrass, hairy galinsoga, ivyleaf morningglory, jimsonweed, johnsongrass, large crabgrass, Mexican groundcherry, pitted morningglory, redroot pigweed, sicklepod, and velvetleaf were tested. In 2003, treatments (expressed as g / ha) were 17.3 cloransulam-methyl, 70.1 and 105.4 flumioxazin, 25.8 and 38.7 halosulfuron, 34.4 and 51.6 imazamox, 275 metribuzin, 1.6 and 2.6 thifensulfuron, and 7.8, 15.7, and 31.4 trifloxysulfuron sodium. With the exception of cloransulam-methyl at Clinton which caused 11% injury, cloransulam-methyl, flumioxazin and imazamox gave 24% or greater visual injury to tomato. Likewise, marketable fruit weight was 16 to 71% of the nontreated check for these herbicides. Tomato was injured 5% or less by all rates of halosulfuron, metribuzin, thifensulfuron, and trifloxysulfuron sodium and yielded similar to tomato in the nontreated control for these treatments. Thus cloransulam-methyl, flumioxazin, and imazamox were too injurious to tomato and excluded from 2004 studies. In 2004,

[1] Received for publication date, and in revised form date.

[2] Graduate research assistant and professor, Department of Horticultural Science, NC State University, Raleigh, NC 27695.

treatments were 5.6, 8.4, 11.2, 16.8, and 33.4 trifloxysulfuron sodium, 275 metribuzin, 3.7, 4.7, and 5.8 thifensulfuron, and 38.7 halosulfuron. Again no differences from the non-treated control were found for tomato yield for these herbicides. Trifloxysulfuron sodium controlled apple of Peru, eastern black nightshade, jimsonweed, and Mexican groundcherry. Thifensulfuron controlled redroot pigweed, velvetleaf, Mexican groundcherry, hairy galinsoga, and jimsonweed. Metribuzin and halosulfuron consistently provided excellent control of Mexican groundcherry, velvetleaf, redroot pigweed, hairy galinsoga, and jimsonweed. Metribuzin consistently provided excellent control of sicklepod, apple of Peru, and eastern black nightshade.

Nomenclature: Apple of Peru, *Nicandra physolodes* #[3] NICPH**;** eastern black nightshade, *Solanum ptycanthum* Dun. # SOLPT; fall panicum, *Panicum dichotomiflorum* Michx. # PANDI; goosegrass, *Eleusine indica* (L.) Gaertn. # ELEIN; hairy galinsoga, *Galinsoga ciliata* (Raf.) Blake # GASCI; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. # IPOHE; jimsonweed, *Datura stramonium* L. # DATST; johnsongrass, *Sorghum halapense* (L.) Pers. # SORHA; large crabgrass, *Digitaria sanguinalis* (L.) Scop. # DIGSA; Mexican groundcherry, *Physalis ixocarpa* Brot. ex Hornem. # PHYIX; pitted morningglory, *Ipomoea lacunosa* L. # IPOLA; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; sicklepod, *Senna obtusifolia* L. # CASOB; tomato, *Lycopersicon esculentum*; velvetleaf, *Abutilon theophrasti # ABUTH*.

Additional index words: Imidazolinone, N-phenylphthalimide, sulfonylurea, triazinone, triazolopyrimidine.

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

Introduction

North Carolina ranks tenth in the United States for fresh market tomato production, and all tomatoes in this state are destined for fresh market sales (North Carolina State University Extension Service 1999). Internationally, the United States is the second leading supplier of tomato (FAOSTAT 2004). Many North Carolina growers use plasticulture because tomatoes grown using this method can produce increased rate of basal branch appearance, total plant growth, early flowering, and early yield of tomato (Maynard and Hochmuth 1997, Wien and Minotti 1987 and 1988), as well as suppress most weed seed germination and growth if using black plastic mulch (Teasdale and Colacicco 1985). However, one disadvantage of this production system is the competition caused by weed seeds not killed during fumigation or that originate from row middles that germinate and establish in openings in the plastic near tomato plants. Close proximity of weed and crop can increase weed/crop interference (Monks and Oliver 1988, Pike et al. 1990). Several options exist to control weeds in the middles between tomato rows, but more options are needed to control weeds in-row in this production system. The phase-out of methyl bromide in 2005 (EPA 1990) will likely increase the probability of weed seed germination and establishment in-row, and increase the importance of this problem. Solanaceous weeds like eastern black nightshade (*Solanum ptycanthum*) are closely related to tomato, so eastern black nightshade control by herbicides is difficult without injuring tomato (Gorski and Wertz 1987). Nightshade has been shown to reduce yields in bare ground tomato production (McGiffen et al. 1992, Perez and Masiunas 1990, Weaver et. al. 1987).

In North Carolina, postemergence control of yellow and purple nutsedge, and broadleaf weeds, such as common cocklebur, common ragweed, hairy galinsoga, redroot and smooth pigweed, and velvetleaf, growing within the row can be controlled with halosulfuron (postemergence over tomato or directed) starting at 14 days after transplanting. In bareground tomato, metribuzin can be applied postemergence-directed after tomato recovers from transplant shock to control annual grasses and broadleaf weeds, such as common lambsquarters, common ragweed, hairy galinsoga, jimsonweed, most pigweeds, purslane (pink and common), and sicklepod. Clethodim and sethoxydim control annual and perennial grasses postemergence but must be applied at least 20 days before harvest (Monks and Mitchem 2005). In Florida and Georgia, in-row weeds such as common cocklebur, common lambsquarters, common ragweed, johnsongrass, some morningglories, yellow and purple nutsedge, some pigweeds, purslane, sicklepod, and velvetleaf also can be treated with trifloxysulfuron sodium postemergence-directed after 14 days after transplanting, but at least 45 days prior to harvest (Stall 2004).

Our objectives were to identify those herbicides that could be registered postdirected in plasticulture tomato and to determine the effect of herbicides postdirected at various rates on tomato injury and weed suppression.

Materials and Methods

Field studies were conducted in 2003 and 2004. In 2003, a study was conducted to identify postemergence-directed herbicides that were safe to tomato. In 2004, a study was conducted to determine rates of the herbicides identified as safe in 2003 that effectively control broadleaf weeds. In 2003, the first location was the Horticulture Crops Research Station in Clinton, NC (35.02 degrees N, 78.28 degrees W, elevation 48 m). Soil was an Orangeburg sandy loam (fine loamy, siliceous, thermic, Typic Paleaudult) with pH 5.7 and humic matter 0.51%. Fertilizer was broadcast incorporated with 90 kg N, P_20_5, and K_2O / ha before soil bedding and plastic mulch application. The second location for the 2003 study was the Mountain Horticultural Crops Research Station in Fletcher, NC (82.56 degrees N, 35.43 degrees W, elevation 631 m). Soil was a Bradson gravelly loam (clayey, oxidic, mesic Typic Hapludults) with pH 6.2 and humic matter 0.56%. Fertilizer was broadcast incorporated with 83, 214, and 138 kg N, P_20_5, and K_2O / ha before soil bedding and plastic mulch application. In 2004, the second study was conducted at Fletcher, where soil was a Comus fine sandy loam (coarse-loamy, mixed, mesic Fluventic Dystrochrepts) with pH 6.2 and humic matter 1.31%. Fertilizer was broadcast incorporated with 84, 316, and 185 kg N, P_20_5, K_2O ha^{-1}, respectively, before soil bedding and plastic mulch application. Dolomitic lime was also incorporated at 2240 kg / ha. In all studies, methyl bromide was applied under the plastic, and weekly fertigation schedules and plasticulture practices were followed as recommended by NC Cooperative Extension Service (Sanders et al. 1995).

Seven-week old fresh market, determinate cultivar 'Amelia'[4] tomato transplants approximately 20 cm tall with 4 to 5 true leaves were hand planted using a 6.5 cm diameter bulb planter to open the holes in the plastic on June 4, 2003 and June 14, 2004 at Fletcher, and May 13, 2003 at Clinton. Plot size was 1.5 by 5.5 m. Plots were single-row plantings of four tomato plants. The other two-thirds of each plot consisted of 14 holes with different weed species sown to each hole. Row centers were 1.5 m apart; space between plants within the row was 45 cm. To avoid shading of neighboring plots, 91 cm were left between each plot within the row. Plastic bed width was 70 cm at the base and 63 cm at the top. Height of the beds from base to ridge was approximately 16 cm. Row middles were maintained weed-free by applying napropramide at 4.5 kg/ha after planting and paraquat at 0.6 kg/ha postemergence as needed. Weeds growing within the same holes as tomato were removed by hand.

In 2003, weed species that infest tomato in NC (NC State University Extension Cooperative Service 1999) were included in the test: eastern black nightshade, fall panicum, goosegrass, hairy galinsoga, ivyleaf morningglory, jimsonweed, johnsongrass, large crabgrass, Mexican groundcherry, pitted morningglory, redroot pigweed, sicklepod, and velvetleaf. Approximately 10 to 25 seeds of each species were sown into separate holes within 24 h of tomato planting. In 2004, goosegrass, johnsongrass, large crabgrass, and fall panicum were eliminated due to lack of herbicidal activity on these species in 2003 studies. Apple of Peru was added to the study in 2004.

Weeds were thinned after emergence to three per hole. Stand counts at time of herbicide application documented weed presence and were taken into account during visual injury determinations. Herbicidal treatments were applied on June 2, 2003 at Clinton and on June 20, 2003 and July 1, 2004 at Fletcher. Tomato growth stage at time of application was pre-bloom, 30 centimeters tall, and prior to sucker removal. All weed seedlings had true leaves and were not taller than 7.5 cm at time of chemical application, except for johnsongrass, which was approximately 9 cm.

Application equipment was a CO_2 backpack sprayer pressurized at 220-234 kPa using a flat fan 8002XR nozzle to apply 187 L/ha spray volume. The single nozzle applied the herbicide solution down each side of the tomato row to the bottom 10 cm of tomato stem, and over the top of the weeds.

At both locations and over both years, experimental design was a randomized complete block design. In 2003, treatments (expressed as g / ha) were 17.3 cloransulam-methyl (based on Firstrate™ soybean postemergence application label of 17.3), 70.1 and 105.4 flumioxazin (based on Valor™ peanut and soybean label of 71.4 to 107.1), 25.8 and 38.7 halosulfuron (based on Sandea™ tomato label), 34.4 and 51.6 imazamox (based on Raptor™ soybean label of 35 to 43.8), 275 metribuzin (Sencor™ tomato label), 1.6 and 2.6 thifensulfuron (based on the Harmony GT™ soybean label of 4.4), 7.8 , 15.7, and 31.4 trifloxysulfuron sodium (based on Envoke™ tomato label for FL and GA). In 2004, treatments were 5.6, 8.4, 11.2, 16.8, and 33.4 trifloxysulfuron sodium, 275 metribuzin, 3.7, 4.7, and 5.8 thifensulfuron, and 38.7 halosulfuron (Table 1). Non-ionic surfactant[5] at 0.25% volume per volume was added to all treatments except metribuzin.

Visual ratings of tomato injury and weed control were made 1, 2, and 4 WAT (weeks after treatment) using a scale from 0 to 100%, with 0 = no injury and 100 = plant death. At two and four WAT, tomato canopy heights were obtained by measuring all four plants within each plot and calculating the average. All four tomato plants within each plot were harvested. Hand harvest began when approximately 5% of all fruit were at the physiological fruit stage of breaker. The stage was usually evident when a yellowish-tan star formed at the blossom end. Harvested stage at subsequent harvests was fruit breaker stage to red. Fruits were harvested three times in 2003 and four times in 2004. The final harvest consisted of removal of all fruit 5 cm in diameter and larger, regardless of color classification. Fruits were graded into marketable and culls (Anonymous 1997), then weighed and counted for each category.

Percent injury and control ratings were arcsine transformed to correct for non-homogeneity of variance. Analysis of variance was then determined and means were separated by Fisher's protected least significant difference at the 5% level. Tables appropriate for the interactions present were constructed. For 2004, crop canopy height and percent control ratings were separately regressed on trifloxysulfuron sodium and thifensulfuron rate, to determine optimal weed control as affected by rate.

Results and Discussions

2003. *Crop Response*. With the exception of cloransulam-methyl at Clinton which caused 11% injury, cloransulam-methyl, flumioxazin and imazamox postemergence-directed gave 24% or greater visual injury to tomato (Tables 3 and 4). Imazomox caused the greatest injury (40 to 83%) among treatments to tomato. Cloransulam-methyl, flumioxazin and imazamox also reduced tomato height (35 to 55.8 cm tall compared to 83.3 cm for the nontreated check) at Fletcher (Table 4). However, 103.4 g/ha flumioxazin and 17.3 g/ha cloransulam-methyl did not reduce tomato height at Clinton (Table 3).

In 2003, injury to tomato from cloransulam-methyl, flumioxazin and imazamox resulted in reductions in fruit number and weight over both locations in 2003. Marketable fruit number was 40, 4, 72, 74, and 73% of the nontreated check for 34.4 and 51.6 kg/ha imazamox, 69.3 and 103.4 g/ha flumioxazin, and 17.3 g/ha cloransulam-methyl, respectively. Likewise, marketable fruit weight was 25, 16, 69, 71, and 65% of the nontreated check for 34.4 and 51.6 kg/ha imazamox, 69.3 and 103.4 g/ha flumioxazin, and 17.3 g/ha cloransulam-methyl, respectively. With the exception of imazamox, cull fruit number did not differ among treatments. Likewise, cull fruit weight did not differ among treatments except imazamox and 69.3 kg/ha flumioxazin (Table 2). Other researchers have also reported tomato injury from postemergence herbicides such as acifluorfen, bentazon, metribuzin, and pyridate (McGiffen and Masiunas 1991).

Tomato was injured 5% or less by all rates of halosulfuron, metribuzin, thifensulfuron, and trifloxysulfuron sodium postemergence-directed (Tables 3 and 4). Over both locations, these treatments yielded similar to tomato in the nontreated control (Table 2). Although metribuzin is labeled for postemergence directed use in bareground tomatoes, caution should be exercised by growers as tomato injury has been reported on certain cultivars (Gawronski 1983, Stephenson 1976). Shorter season cultivars could be susceptible to injury by this herbicide (Gawronski 1983).

Imazamox, flumioxazin, and cloransulam-methyl were too injurious to tomato relative to the other treatments and use in tomato production would not be desirable. However, thifensulfuron, trifloxysulfuron sodium, halosulfuron, and metribuzin were safe to tomato at both locations and likely would be useful to growers developing weed management programs for tomato.

Annual Grass Control. In 2003, flumioxazin and metribuzin gave 80 to 99% control of fall panicum (Table 5). All other treatments gave control that was not acceptable with imazamox giving 48 to 49%, and cloransulam-methyl, halosulfuron, thifensulfuron, and trifloxysulfuron sodium giving 0 to 24% control of fall panicum. Similar results among treatments were observed for goosegrass and large crabgrass (except for imazamox). Imazamox at 34.4 and 51.6 g/ha gave 75 and 79% control of large crabgrass, respectively (Table 5).

Eastern Black Nightshade Control. With the exception of cloransulam-methyl, thifensulfuron, 7.8 and 15.7 g/ha trifloxysulfuron sodium (Fletcher), and halosulfuron (both locations) gave 81% or greater control of eastern black nightshade (Tables 3 and 4). Variability in control by cloransulam-methyl, thifensulfuron and trifloxysulfuron sodium may be due to nightshade plant size being variable at each location and greater control occurs when these herbicides are applied to small weeds. Metribuzin applied postemergence has not generally given high or consistent control of eastern black nightshade (Hermanutz and Weaver 1994, Ogg 1986, McGiffen and Masiunas 1991), but this study shows excellent control, again probably due to small weed size.

Hairy Galinsoga Control. With the exception of imazamox (51.6 g/ha at Clinton) and 7.8 and 15.7 g/ha trifloxysulfuron sodium at Fletcher, all herbicide treatments gave 92% or greater hairy galinsoga control. Imazamox and trifloxysulfuron sodium did not consistently control hairy galinsoga over both locations. Hairy galinsoga is a common weed in tomato row middles in western and eastern North Carolina, and commonly infests tomato rows that are not fumigated with methyl bromide (D.W. Monks, personal communication).

Ivyleaf Morningglory Control. With the exception of metribuzin (Fletcher), cloransulam-methyl, flumioxazin, and metribuzin herbicide treatments controlled ivyleaf morningglory 81% or better (Tables 3 and 4). Metribuzin applied postemergence has been previously reported to control ivyleaf morningglory (Robinson et al. 1996).

Jimsonweed Control. All treatments except 7.8 g/ha trifloxysulfuron sodium provided similar jimsonweed control of 82% or better (Table 5). Metribuzin applied postemergence has been previously reported to control jimsonweed (Robinson et al.

1996). Similar results were found when metribuzin applied postemergence provided 63 and 75% control 8 WAT (Ackley et al. 1997).

Johnsongrass Control. With the exception of metribuzin (Fletcher) and cloransulam (Fletcher), cloransulam-methyl, the high rate of flumioxazin, imazamox, and metribuzin provided 66% or better control of johnsongrass (Tables 3 and 4).

Mexican Groundcherry Control. Cloransulam-methyl, imazamox, flumioxazin, and metribuzin provided consistent control of Mexican groundcherry of 85% or better. With the exception 15.7 g/ha trifloxysulfuron sodium (Clinton), halosulfuron and 15.7 and 31.4 g/ha trifloxysulfuron sodium provided 72% Mexican groundcherry control or higher (Tables 3 and 4).

Pitted Morningglory Control. Cloransulam-methyl and flumioxazin controlled pitted morningglory consistently at 99% or higher. Halosulfuron and metribuzin provided 67% control or better (Tables 3 and 4).

Redroot Pigweed Control. In Clinton, redroot pigweed was treated above the targeted application rate due to close proximity of the weed with the tomato plants in the plot, therefore was withdrawn from statistical analyses. At Fletcher, flumioxazin, halosulfuron, imazamox, metribuzin, thifensulfuron, and the high rate of trifloxysulfuron sodium provided 98% control or higher of redroot pigweed (Table 4). Metribuzin applied postemergence has been previously reported to control redroot pigweed (Robinson et al. 1996).

Sicklepod Control. In Clinton, sicklepod was treated above the targeted application rate due to close proximity of the weed with the tomato plants in the plot, therefore was withdrawn from statistical analyses. At Fletcher, cloransulam-methyl, flumioxazin, halosulfuron, and metribuzin provided 81% control or higher of sicklepod (Table 4).

Velvetleaf Control. With the exception of 51.6 g/ha imazamox (Clinton) and 2.6 g/ha thifensulfuron (Clinton), cloransulam-methyl, flumioxazin, halosulfuron, imazamox, metribuzin, and thifensulfuron provided 75% or better control of velvetleaf. Metribuzin has previously been reported to control velvetleaf (McGiffen and Masiunas 1991).

2004. *Crop Response*. Because imazamox, flumioxazin, and cloransulam-methyl caused unacceptable injury to tomato in 2003, these herbicides were not included in 2004. In 2004, non-registered herbicides thifensulfuron and trifloxysulfuron sodium were expanded to include more rates (3.7, 4.7, and 5.8 g / ha thifensulfuron and 5.6, 8.4, 11.2, 16.8, and 33.4 g / ha trifloxysulfuron sodium) for the purpose of establishment of optimal rate responses. In 2004, no differences were found for tomato yield among trifloxysulfuron sodium, thifensulfuron, and the commercially registered rates of metribuzin or halosulfuron (data not shown).

Due to the lack of control in 2003 of fall panicum, goosegrass, johnsongrass, and large crabgrass by any non-registered herbicide used in this study, these weeds were excluded in 2004.

Weed control by metribuzin and halosulfuron were consistent with 2003, except for halosulfuron, for which good control (75-90%) for sicklepod was provided in Fletcher for 2003, compared to no control in 2004, and Mexican groundcherry for which good control was provided in 2003 compared to excellent (90 to 100%) control for 2004. Again, metribuzin and halosulfuron provided excellent control of Mexican groundcherry, velvetleaf, redroot pigweed, hairy galinsoga, and jimsonweed; metribuzin provided excellent control of sicklepod, apple of Peru, and eastern black nightshade.

Ivyleaf morningglory was not controlled by any rate of trifloxysulfuron sodium, therefore could not be regressed (data not shown). Regression analyses for crop canopy height, crop injury, and weed control, as influenced by rate of trifloxysulfuron sodium, showed crop canopy height, tomato crop injury, and control of hairy galinsoga, pitted morningglory, redroot pigweed, and velvetleaf to be non-significant (Table 6). Sicklepod was not controlled at least 75% at the rates tested (data not shown), consistent with results from Fletcher in 2003. The supplemental label[6] for Envoke™ shows control of sicklepod applied postemergence-directed on tomato at 5.25 to 10.5 g/ha; and if applied at higher rates or repeated applications, of redroot pigweed and velvetleaf; and recommended at the 1 to 2 leaf stage, of pitted and ivyleaf morningglories. The latter four weeds did not show a rate response in this test. The morningglories had four true leaves instead of the recommended two. Redroot pigweed showed no significant regression model, velvetleaf showed no significant rate response, and sicklepod was not controlled at any rate, despite all three of these weeds being within the weed size ranges for optimum control as listed on the label. Consistent with 2003 at the higher rate of trifloxysulfuron sodium, Mexican groundcherry, eastern black nightshade and jimsonweed were controlled (Table 6). Apple of Peru was also controlled (Table 6). To achieve 85% control, regression analysis predicted trifloxysulfuron sodium must be applied at 17.9 g/ha for jimsonweed, 24.7 g ai/ha for Mexican groundcherry, and 26.3 g/ha for apple of Peru and eastern black nightshade. These predicted rates are higher than the maximum 15.8 g per season as specified on the label.

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[6]Syngenta Crop Protection, Inc. Greensboro, NC 27490.

Regression analyses for crop canopy height, crop injury, and weed control, as influenced by rate of thifensulfuron, showed crop canopy height, tomato injury, and control of apple of Peru, eastern black nightshade, ivyleaf morningglory, and sicklepod to be non-significant (Table 7). Pitted morningglory did not have at least 75% control at the rates tested (data not shown) therefore provided unacceptable control, consistent with results in 2003. In 2003, in which the thifensulfuron rates were lower, redroot pigweed, hairy galinsoga, and jimsonweed were also controlled. Velvetleaf was controlled with good to excellent results in Fletcher but not in Clinton in 2003, and Mexican groundcherry was not controlled in 2003 (Tables 3 and 4). To achieve 85% control, regression analyses predicted thifensulfuron must be applied at 3.2 g/ha for redroot pigweed, Mexican groundcherry, and jimsonweed, 3.7 g/ha for hairy galinsoga, and 4.2 g/ha for velvetleaf.

In summary, ‘Amelia’ tomato was tolerant of trifloxysulfuron sodium and thifensulfuron at all rates tested when applied postemergence-directed. Trifloxysulfuron sodium controls apple of Peru, eastern black nightshade, jimsonweed, and Mexican groundcherry. Thifensulfuron controls redroot pigweed, velvetleaf, Mexican groundcherry, hairy galinsoga, and jimsonweed. Both herbicides have the potential to be useful parts of integrated pest management programs for plasticulture tomato growers.

Future research with trifloxysulfuron sodium and thifensulfuron should focus on tankmixing with each other, halosulfuron and/or metribuzin to determine their weed control effectiveness when applied postemergence-directed, and more precise application technique to reduce nontarget application onto the plastic beds.

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Sources of Materials

[4]'Amelia' tomato, Harris Moran Seed Company, P.O. Box 4938, Modesto, CA 95352.

[5]X-77, Loveland Industries, Inc., P.O. Box 1289, Greely, CO 80632.

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Table 1. Common name, trade name, formulation, and application rates of herbicides used in herbicide evaluation studies.

Common name	Trade name	Formulation	2003	2004
			g ai /ha	
cloransulam-methyl	Firstrate	84 WG	17.3	-
flumioxazin	Valor	51 WG	70.1, 105.4	-
halosulfuron	Sandea	75 WG	25.8, 38.7	38.7
imazamox	Raptor	12.1 AS	34.4, 51.6	-
metribuzin	Sencor	75 DF	275	275
thifensulfuron	Harmony	75 DF	1.6, 2.6	3.7, 4.7, 5.8
trifloxysulfuron sodium	Envoke	80 WG	7.8, 15.7, 31.4	5.6, 8.4, 11.2, 16.8, 33.4

Table 2. The effect of various post-directed herbicides on tomato fruit yield[a].

Treatment	Rate	Fruit					
		Marketable		Cull		Total	
	g/ha	Number 1000 fruits/ha	Weight 1000 kg/ha	Number 1000 fruits/ha	Weight 1000 kg/ha	Number 1000 fruits/ha	Weight 1000 kg/ha
Nontreated	0	314.9	71.3	37.4	5.8	352.3	77.2
cloransulam	17.3	231.4	46.6	27.4	4.8	258.8	51.5
flumioxazin	69.3	225.3	49.1	20.6	2.9	245.9	51.9
	103.4	234.5	50.7	26.3	3.8	260.7	54.5
halosufuron	25.8	353.6	78.9	33.9	5.9	387.5	84.7
	38.7	352.1	79.4	25.1	4.7	377.2	84.0
imazamox	34.4	124.8	18.0	19.0	2.3	143.9	20.3
	51.6	11.1	11.4	4.2	0.4	15.2	1.5
metribuzin	275	350.9	74.8	25.5	4.7	376.5	79.5
thifensulfuron	1.5	347.1	76.6	30.4	5.4	377.6	82.1
	2.6	296.9	64.9	29.7	4.7	326.6	69.6
trifloxysulfuron	7.8	347.1	77.9	27.4	5.6	374.5	83.5
	15.7	321.9	74.1	30.4	5.7	352.3	79.8
	31.4	351.7	78.7	27.0	3.5	378.7	82.2
LSD(.05)		69.8	14.7	18.6	2.6	72.4	15.1

[a]Data combined over two sites for 2003.

Table 3. The effect of various post-directed herbicides on tomato and weeds, Clinton, NC, 2003[a].

Treatment	Rate	Tomato		Weed						
		Plant height	Injury	IPOLA[b]	ABUTH	SORHA	IPOHE	PHYIX	SOLPT	GASCI
	g/ha	cm	%							
nontreated	0	87.0	0	0	0	0	0	0	0	0
cloransulam	17.3	78.6	11	100	91	68	81	100	100	100
flumioxazin	69.3	77.1	24	100	100	59	100	100	100	100
	103.4	81.6	34	100	100	74	100	100	100	100
halosufuron	25.8	87.4	0	73	100	0	71	100	5	100
	38.7	86.1	0	74	100	0	0	87	71	100
imazamox	34.4	64.8	40	0	77	94	3	85	100	97
	51.6	45.7	68	3	51	78	0	94	97	55
metribuzin	275	84.7	0	92	100	100	87	100	100	100
trifloxysulfuron	7.8	84.7	0	0	0	0	0	71	100	92
	15.7	85.1	1	0	38	0	0	42	100	94
	31.4	90.9	1	0	39	50	38	100	81	100
thifensulfuron	1.5	85.6	3	50	100	1	71	100	92	100
	2.6	88.6	0	75	52	0	50	46	87	100
LSD(.05)		8.6	14	67	68	67	86	60	62	52

[a]Visual ratings at 4 weeks after treatment using a 0 to 100 % scale, with 0 = no control or injury and 100 = complete control or crop death.

[b]Weed name abbreviations: IPOLA, pitted morningglory; ABUTH velvetleaf; SORHA Johnsongrass; IPOHE, ivyleaf morningglory; PHYIX, Mexican groundcherry; SOLPT, eastern black nightshade; GASCI, hairy galinsoga.

Table 4. The effect of various post-directed herbicides on tomato and weeds, Fletcher, NC, 2003[a].

		Tomato		Weed								
Treatment	Rate	Plant height	Injury	CASOB[b]	AMARE	IPOLA	ABUTH	SORHA	IPOHE	PHYIX	SOLPT	GASCI
	g/ha	cm	%									
nontreated	0	83.3	0	0	0	0	0	0	0	0	0	0
cloransulam	17.3	55.8	45	99	55	99	100	13	100	100	33	100
flumioxazin	69.3	41.8	61	100	100	100	75	45	100	100	100	100
	103.4	46.8	49	100	100	100	100	71	100	100	100	100
halosufuron	25.8	84.3	3	85	100	67	100	38	14	72	0	100
	38.7	83.9	0	81	100	85	100	3	21	83	0	100
imazamox	34.4	35	80	78	100	59	100	85	73	100	100	99
	51.6	35.7	83	68	100	65	96	66	79	100	100	100
metribuzin	275	81.8	0	100	100	70	100	21	6	100	100	100
thifensulfuron	1.5	84.4	0	0	100	14	76	0	8	45	38	94
	2.6	80.8	5	10	100	38	100	0	16	53	0	99
trifloxysulfuron	7.8	84.5	0	14	10	8	5	0	0	5	0	8
	15.7	82.6	3	24	43	18	8	0	38	93	72	80
	31.4	83.5	3	40	98	52	29	3	15	100	100	99
LSD(.05)		12.5	21	32	21	46	44	57	31	44	49	37

[a]Visual ratings at 4 weeks after treatment using a 0 to 100 % scale, with 0 = no control or injury and 100 = complete control or crop death.

[b]Weed name abbreviations: CASOB, sicklepod; AMARE, redroot pigweed; IPOLA, pitted morningglory; ABUTH, velvetleaf; SORHA, Johnsongrass; IPOHE, ivyleaf morningglory; PHYIX, Mexican groundcherry; SOLPT, eastern black nightshade; GASCI, hairy galinsoga.

Table 5. Control of four weed species with various post-directed herbicides combined over Clinton and Fletcher for 2003[a].

Treatment	Rate	DIGSA[b]	ELEIN	PANDI	DATST
	g/ha		%		
nontreated	0	0	0	0	0
cloransulam	17.3	12	20	23	100
flumioxazin	69.3	98	72	99	100
	103.4	83	85	80	100
halosufuron	25.8	0	0	0	100
	38.7	20	0	0	100
imazamox	34.4	75	25	48	100
	51.6	79	21	49	100
metribuzin	275	71	75	88	100
thifensulfuron	1.5	0	22	24	82
	2.6	0	0	0	86
trifloxysulfuron	7.8	0	0	0	9
	15.7	0	20	0	95
	31.4	20	0	4	97
LSD(.05)		51	46	41	38

[a]Visual ratings at 4 weeks after treatment using a 0 to 100 % scale, with 0 = no control or injury and 100 = complete control or crop death.

[b]Weed name abbreviations: DIGSA, large crabgrass; ELEIN, goosegrass; PANDI, fall panicum; DATST, jimsonweed.

Table 6. Regression analyses for tomato plant height, tomato injury, and weed control as influenced by rate of trifloxysulfuron for 2004.

Parameter	P-value	F-value	Equation	R^2	
Tomato plant height	0.3480	1.19	Y=73-21.3x	0.20	NS
Tomato injury*	0.0040	5.53	Y=0.007-0.03x	0.54	NS
Apple of Peru	0.0027	6.00	Y=0.21+1.63x	0.56	
Eastern black nightshade	0.0014	6.86	Y=-0.31+2.64x	0.59	
Hairy galinsoga*	0.0012	7.41	Y=-0.01+0.34x	0.64	NS
Ivyleaf morningglory**					NS
Jimsonweed	<0.0001	12.16	Y=0.043+2.9x	0.72	
Mexican groundcherry	0.0039	5.57	Y=-0.25+2.67x	0.54	
Pitted morningglory	0.1214	2.11	Y=-0.014+0.06x	0.32	NS
Redroot pigweed	0.1779	1.77	Y=0.3-0.17x	0.28	NS
Sicklepod	0.0337	3.27	Y=0.01+0.143x	0.41	
Velvetleaf*	0.2298	1.54	Y=0.08+0.16x	0.25	NS

*No significant treatment effect.

**No control at any rate, therefore could not be regressed.

Table 7. Regression analyses for tomato plant height, tomato injury, and weed control as influenced by rate of thifensulfuron for 2004.

Parameter	P-value	F-value	Equation	R^2	
Tomato plant height	0.3740	1.18	Y=59.27+239.86x	0.30	NS
Tomato injury	0.5645	0.77	Y=-0.01+0.08x	0.22	NS
Apple of Peru	0.5354	0.83	Y=0.12+4.77x	0.23	NS
Eastern black nightshade	0.4400	1.02	Y=0.04+0.47x	0.27	NS
Hairy galinsoga	0.0002	15.85	Y=0.07+14.34x	0.85	
Ivyleaf morningglory	0.5223	0.86	Y=0.11+6.13x	0.28	NS
Jimsonweed	<0.0001	23.73	Y=0.06+14.89x	0.91	
Mexican groundcherry	0.0006	11.84	Y=0.15+15.28x	0.81	
Pitted morningglory	0.0005	11.91	Y=0.06+1.80x	0.81	
Redroot pigweed	<0.0001	20.88	Y=0.14+15.42x	0.88	
Sicklepod	0.3879	1.14	Y=-0.02+0.31x	0.29	NS
Velvetleaf	0.0060	6.53	Y=0.05+12.63x	0.70	

APPENDICES

Appendix Table 1. Tomato leaf tissue nutrient sampling dates at various weeks after tomato transplanting (WAP), Fletcher, NC, for tomatoes planted June 4, 2003 and June 14, 2004.

WAP	Sampling Date	
	2003	2004
5		X
6	X	X
7	X	X
8	X	X
9	X	X
10	X	
11	X	

Appendix Table 2a. Tomato leaf tissue concentrations averaged over sampling dates for tomato grown with eastern black nightshade that was established at various weeks after tomato planting (WAP), Fletcher, NC, 2003 and 2004[1].

Weed Establishment	Mineral Nutrient														
WAP	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Na	N:S	N:K	Fe:Mn
	%						ppm					%			
1	3.8	0.3	2.2	2.4	0.5	0.5	71.5	140.6	30.1	293.2	74.6	0.02	7.6	1.7	0.6
2	4.0	0.3	2.4	2.3	0.5	0.5	70.2	144.2	30.3	266.2	69.1	0.03	8.2	1.7	0.6
3	3.9	0.3	2.3	2.4	0.6	1.9	68.8	119.7	30.4	296.1	72.5	0.02	7.7	1.7	0.7
4	3.9	0.3	2.3	2.3	0.5	0.5	74.3	134.4	30.0	278.3	73.1	0.02	8.1	1.7	0.7
5	4.0	0.3	2.3	2.4	0.6	0.5	77.0	145.1	29.4	258.8	68.8	0.02	7.9	1.7	0.7
6	3.9	0.3	2.3	2.4	0.6	0.5	74.5	147.6	29.8	266.0	66.7	0.02	7.8	1.8	0.7
12	3.9	0.3	2.2	2.4	0.5	0.5	77.6	111.3	29.0	325.3	75.3	0.02	8.2	1.8	0.8
LSD(.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]Data are combined over 2003 and 2004 because no interactions were present at the $p \leq 0.05$ level.

Appendix Table 2b. Tomato leaf tissue concentrations averaged over sampling dates for tomato grown with eastern black nightshade that was removed at various weeks after tomato planting (WAP), Fletcher, NC, 2003 and 2004[1].

Weed Removal	Mineral Nutrient											
WAP	N	P	K	Ca	Mg	Fe	Zn	Cu	B	Na	N:K	Fe:Mn
	%					ppm				%		
2	3.7	0.3	2.3	2.4	0.5	77.8	29.0	294.9	75.3	0.02	1.7	0.7
3	4.1	0.3	2.3	2.4	0.6	73.4	32.5	239.6	63.1	0.02	1.8	0.7
4	3.9	0.3	2.3	2.4	0.6	79.3	27.8	248.9	67.9	0.02	1.7	0.7
5	3.8	0.3	2.3	2.4	0.6	68.4	27.1	264.3	72.4	0.02	1.7	0.6
6	3.9	0.3	2.4	2.3	0.5	69.5	30.0	288.6	71.5	0.02	1.7	0.5
8	4.1	0.3	2.4	2.3	0.6	83.7	29.2	268.6	72.7	0.02	1.7	0.8
12	3.9	0.3	2.3	2.4	0.5	83.2	29.5	281.8	73.9	0.02	1.7	0.9
LSD(.05)	0.24	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]Data are combined over 2003 and 2004 because no interactions were present at the $p \leq 0.05$ level.

Appendix Table 2c. Tomato leaf tissue sulfur, manganese, and nitrogen : sulfur concentrations averaged over sampling dates for tomato grown with eastern black nightshade that was removed at various weeks after tomato planting (WAP), Fletcher, NC, 2003 and 2004[1].

Weed Removal	Mineral Nutrient					
	2003			2004		
WAP	S	Mn	N:S	S	Mn	N:S
	%	ppm		%	ppm	
2	0.6	104.2	6.7	0.5	163.1	8.6
3	0.6	107.8	7.2	0.5	165.9	10.1
4	0.5	123.8	7.2	0.5	149.8	8.9
5	0.5	109.8	7.2	0.5	163.4	7.8
6	0.5	143.9	7.7	0.6	166.4	7.6
8	0.6	203.3	7.6	0.5	140.4	8.5
12	0.6	94.6	6.3	0.5	137.1	8.2
LSD(.05)	NS	27.0	NS	0.06	NS	1.0

[1]Data are presented separately by year because interactions between year and treatment were present at the $p \leq 0.05$ level.

Appendix Table 3. Tomato leaf tissue concentrations sampled at 5 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2004.

Weed EST	Mineral Nutrient							Weed REM	Mineral Nutrient						
WAP	N	P	K	Ca	Mg	S	Na	WAP	N	P	K	Ca	Mg	S	Na
	%								%						
1	5.1	0.5	2.5	1.6	0.5	0.6	0.03	2	4.8	0.5	2.3	1.5	0.5	0.6	0.03
2	5.2	0.5	2.4	1.6	0.5	0.6	0.03	3	5.1	0.5	2.2	1.5	0.5	0.6	0.03
3	5.1	0.5	2.5	1.6	0.6	0.7	0.03	4	5.1	0.5	2.5	1.6	0.5	0.6	0.03
4	5.2	0.5	2.4	1.6	0.5	0.7	0.03	5	4.5	0.5	2.4	1.4	0.5	0.6	0.02
5	5.3	0.5	2.4	1.6	0.6	0.7	0.03	6	4.6	0.5	2.3	1.5	0.5	0.6	0.02
6	5.3	0.5	2.4	1.6	0.5	0.6	0.03	8	4.9	0.5	2.3	1.5	0.5	0.7	0.03
12	5.1	0.5	2.3	1.6	0.5	0.7	0.03	12	5.1	0.5	2.3	1.5	0.5	0.6	0.03
	NS[1]	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS

[1]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 3 (continued). Tomato leaf tissue concentrations sampled at 5 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2004.

Weed EST	Mineral Nutrient								Weed REM	Mineral Nutrient							
WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn	WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn
	ppm									ppm							
1	61.1	130.0	30.1	87.9	63.7	8.4	2.1	0.5	2	50.5	121.5	27.2	83.6	63.0	8.4	2.1	0.5
2	64.0	115.5	29.3	76.0	63.8	8.9	2.2	0.6	3	52.5	138.8	27.9	83.8	64.0	9.3	2.3	0.4
3	56.5	111.2	28.8	79.8	65.8	7.9	2.1	0.6	4	55.9	117.3	27.1	67.9	62.3	8.6	2.0	0.5
4	60.1	120.9	29.3	90.6	66.9	8.3	2.2	0.6	5	49.9	121.1	27.1	80.8	65.1	7.4	1.9	0.5
5	61.1	129.5	32.0	79.1	63.2	8.2	2.2	0.5	6	45.6	122.3	26.1	77.6	64.7	7.2	2.0	0.4
6	51.2	115.9	27.3	84.7	64.8	8.8	2.3	0.5	8	73.8	113.6	29.4	72.8	59.2	8.7	2.1	0.7
12	94.8	109.8	30.0	88.1	67.0	8.4	2.3	0.9	12	62.9	117.6	27.4	75.6	61.6	8.3	2.2	0.6
	NS[1]	NS	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	1.2	NS	NS

[1]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 4. Tomato leaf tissue concentrations sampled at 6 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003 and 2004[1].

Weed EST	Mineral Nutrient							Weed REM	Mineral Nutrient						
WAP	N	P	K	Ca	Mg	S	Na	WAP	N	P	K	Ca	Mg	S	Na
	%								%						
1	3.6	0.3	2.2	1.7	0.5	0.4	0.03	2	3.6	0.3	2.3	1.8	0.5	0.5	0.03
2	3.7	0.3	2.3	1.8	0.5	0.5	0.03	3	4.0	0.3	2.3	1.9	0.6	0.4	0.03
3	3.6	0.3	2.2	1.8	0.5	0.5	0.03	4	4.0	0.3	2.3	1.8	0.5	0.4	0.03
4	3.8	0.3	2.3	1.7	0.5	0.5	0.03	5	3.7	0.3	2.2	1.8	0.5	0.5	0.03
5	4.1	0.3	2.3	1.9	0.6	0.4	0.03	6	3.6	0.3	2.5	1.8	0.5	0.5	0.03
6	3.8	0.3	2.3	1.8	0.6	0.5	0.03	8	3.9	0.3	2.4	1.7	0.5	0.4	0.03
12	4.1	0.3	2.2	1.8	0.5	0.4	0.03	12	3.9	0.3	2.1	1.8	0.5	0.5	0.03
	NS[2]	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS

[1]Data are combined over 2003 and 2004 because no interactions were present at the $p \leq 0.05$ level.

[2]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 4 (continued). Tomato leaf tissue concentrations sampled at 6 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003 and 2004[1].

Weed EST	Mineral Nutrient								Weed REM	Mineral Nutrient							
WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn	WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn
	ppm									ppm							
1	88.6	116.6	35.2	121.9	54.5	8.7	1.7	0.9	2	87.1	116.0	28.8	114.2	53.0	8.1	2.0	0.9
2	89.3	117.7	33.9	106.4	53.4	8.6	1.6	0.9	3	98.5	113.8	35.6	112.5	51.1	9.4	1.8	1.1
3	85.2	94.2	29.4	115.6	53.8	8.1	1.7	1.0	4	111.0	112.7	29.1	103.2	49.6	9.1	1.7	1.1
4	100.8	108.6	30.3	119.7	54.0	8.8	1.7	1.0	5	86.7	108.5	28.2	113.2	53.3	8.4	1.8	1.0
5	93.1	116.3	29.3	115.1	50.3	9.3	1.8	1.0	6	83.4	127.3	29.9	123.0	58.0	7.6	1.5	0.7
6	106.8	128.0	34.9	107.8	50.4	8.6	1.6	1.2	8	112.2	136.5	31.8	116.4	52.1	9.7	1.6	1.3
12	85.7	95.3	28.1	119.1	54.6	10.2	1.9	1.0	12	110.3	90.5	30.0	121.5	54.2	8.3	1.9	1.5
	NS[2]	NS	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS

[1]Data are combined over 2003 and 2004 because no interactions were present at the $p \leq 0.05$ level.

[2]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 5. Tomato leaf tissue concentrations sampled at 7 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003 and 2004[1].

Weed EST	Mineral Nutrient							Weed REM	Mineral Nutrient						
WAP	N	P	K	Ca	Mg	S	Na	WAP	N	P	K	Ca	Mg	S	Na
	%								%						
1	3.8	0.3	2.2	1.8	0.5	0.4	0.02	2	3.8	0.3	2.2	1.8	0.5	0.5	0.02
2	4.1	0.3	2.2	1.7	0.5	0.5	0.02	3	4.3	0.3	2.3	1.8	0.6	0.5	0.02
3	4.1	0.3	2.2	1.8	0.5	0.5	0.02	4	3.9	0.3	2.2	1.8	0.5	0.5	0.02
4	4.0	0.3	2.4	1.8	0.5	0.5	0.02	5	3.6	0.3	2.2	1.8	0.5	0.5	0.02
5	3.8	0.3	2.4	1.9	0.6	0.5	0.03	6	4.0	0.3	2.3	1.7	0.5	0.5	0.02
6	4.1	0.3	2.3	1.8	0.5	0.5	0.02	8	4.3	0.3	2.3	1.8	0.5	0.5	0.02
12	3.8	0.3	2.2	1.8	0.5	0.5	0.02	12	4.1	0.3	2.2	1.8	0.5	0.5	0.02
	NS[2]	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS

[1]Data are combined over 2003 and 2004 because no interactions were present at the $p \leq 0.05$ level.

[2]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 5 (continued). Tomato leaf tissue concentrations sampled at 7 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003 and 2004[1].

Weed EST	Mineral Nutrient								Weed REM	Mineral Nutrient							
WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn	WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn
	ppm									ppm							
1	74.1	133.8	25.3	148.6	58.9	9.0	1.7	0.6	2	76.6	124.7	22.8	182.3	68.1	8.3	1.7	0.8
2	73.5	129.5	26.4	139.0	58.9	9.4	1.9	0.7	3	80.1	128.8	24.2	122.5	55.2	9.3	1.8	0.8
3	72.7	105.9	25.6	163.2	59.8	8.8	1.9	0.7	4	85.8	121.8	23.4	149.2	65.5	8.7	1.8	0.8
4	72.4	123.6	24.8	157.9	64.4	9.1	1.7	0.7	5	62.1	123.8	23.2	165.4	66.4	7.8	1.6	0.7
5	75.7	133.4	24.4	166.8	67.6	8.1	1.6	0.7	6	67.1	137.3	24.9	136.6	59.8	8.5	1.8	0.6
6	78.7	132.9	24.9	136.5	56.7	8.5	1.8	0.8	8	70.6	147.1	25.3	147.7	67.3	9.1	1.8	0.6
12	76.6	106.7	23.2	181.5	68.6	8.5	1.8	0.8	12	71.5	102.3	22.4	155.8	66.1	8.1	1.9	0.9
	NS[2]	NS	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS

[1]Data are combined over 2003 and 2004 because no interactions were present at the $p \leq 0.05$ level.

[2]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 6. Tomato leaf tissue concentrations sampled at 8 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003 and 2004[1].

Weed EST	Mineral Nutrient							Weed REM	Mineral Nutrient					
WAP	N	P	K	Ca	Mg	S	Na	WAP	N	P	Ca	Mg	S	Na
	%								%					
1	3.8	0.3	2.4	2.2	0.6	0.6	0.02	2	3.8	0.3	2.2	0.6	0.6	0.02
2	3.9	0.3	2.6	2.0	0.5	0.5	0.02	3	4.0	0.3	2.3	0.6	0.6	0.02
3	3.8	0.3	2.6	2.2	0.6	0.6	0.02	4	3.9	0.3	2.3	0.6	0.6	0.02
4	3.8	0.3	2.5	2.2	0.6	0.6	0.02	5	4.0	0.3	2.4	0.6	0.6	0.02
5	4.0	0.3	2.5	2.2	0.6	0.6	0.02	6	3.8	0.3	2.3	0.6	0.6	0.02
6	3.8	0.3	2.5	2.2	0.6	0.6	0.02	8	4.1	0.3	2.4	0.6	0.7	0.02
12	3.8	0.3	2.5	2.2	0.6	0.6	0.02	12	3.9	0.3	2.3	0.6	0.6	0.02
	NS[2]	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS

[1]Data are combined over 2003 and 2004 because no interactions were present at the $p \leq 0.05$ level.

[2]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 6 (continued). Tomato leaf tissue concentrations sampled at 8 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003 and 2004[1].

Weed EST	Mineral Nutrient								Weed REM	Mineral Nutrient							
WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn	WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn
	ppm									ppm							
1	72.4	153.1	23.4	229.0	57.4	7.5	1.6	0.5	2	88.9	151.6	24.4	244.6	61.7	7.2	1.5	0.6
2	71.7	155.4	24.7	208.4	56.6	8.3	1.6	0.5	3	77.3	147.9	25.1	190.4	50.5	7.8	1.6	0.7
3	69.5	132.5	23.2	238.5	56.9	7.3	1.6	0.6	4	81.7	150.1	24.0	206.5	57.0	7.2	1.6	0.6
4	73.7	140.0	28.1	233.1	62.5	7.2	1.6	0.6	5	69.9	154.2	22.9	233.9	63.7	6.8	1.7	0.5
5	85.2	154.0	23.2	190.0	51.9	7.8	1.6	0.6	6	69.2	164.5	23.7	208.6	61.7	6.7	1.6	0.5
6	71.2	159.0	21.7	201.3	52.8	7.2	1.6	0.6	8	83.4	200.9	25.9	265.5	69.2	6.7	1.7	0.5
12	82.3	123.9	25.5	210.1	54.3	7.5	1.6	0.7	12	71.3	124.2	22.8	240.9	58.4	6.8	1.6	0.7
	NS[2]	NS	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS

[1]Data are combined over 2003 and 2004 because no interactions were present at the $p \leq 0.05$ level.

[2]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 6b. Tomato leaf tissue potassium concentrations sampled at 8 weeks after planting for eastern black nightshade that was removed at various weeks after tomato planting (WAP), Fletcher, NC, for years 2003 and 2004[1].

Weed Removal	K	
	2003	2004
WAP	%	%
2	3.1	2.3
3	2.6	2.4
4	2.9	2.2
5	2.6	2.2
6	3.0	2.1
8	2.7	2.3
12	2.8	2.3
LSD(.05)	0.3	NS

[1]Data are presented separately by year because interactions between year and treatment were present at the $p \leq 0.05$ level.

Appendix Table 7. Tomato leaf tissue concentrations sampled at 9 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003 and 2004[1].

Weed EST	Mineral Nutrient							Weed REM	Mineral Nutrient						
WAP	N	P	K	Ca	Mg	S	Na	WAP	N	P	K	Ca	Mg	S	Na
	%								%						
1	3.5	0.3	2.1	2.6	0.5	0.5	0.02	2	3.5	0.3	2.1	2.6	0.5	0.5	0.02
2	3.7	0.3	2.2	2.5	0.5	0.5	0.03	3	4.0	0.2	2.0	2.3	0.5	0.5	0.02
3	3.9	0.3	2.2	2.5	0.5	0.5	0.02	4	3.5	0.3	2.1	2.6	0.5	0.5	0.02
4	3.7	0.3	2.1	2.6	0.5	0.5	0.02	5	3.6	0.3	2.2	2.6	0.5	0.5	0.02
5	3.8	0.3	2.1	2.6	0.5	0.5	0.02	6	3.9	0.3	2.2	2.5	0.5	0.5	0.02
6	3.7	0.2	2.0	2.5	0.5	0.5	0.02	8	3.6	0.2	2.1	2.6	0.5	0.6	0.02
12	3.7	0.2	2.1	2.4	0.5	0.4	0.02	12	3.6	0.3	2.3	2.5	0.5	0.6	0.02
	NS[2]	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS

[1]Data are combined over 2003 and 2004 because no interactions were present at the $p \leq 0.05$ level.

[2]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 7 (continued). Tomato leaf tissue concentrations sampled at 9 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003 and 2004[1].

Weed EST	Mineral Nutrient								Weed REM	Mineral Nutrient							
WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn	WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn
	ppm									ppm							
1	85.7	160.3	30.1	103.4	71.1	7.0	1.7	0.6	2	100.3	155.7	24.8	121.1	73.7	7.3	1.6	0.9
2	72.7	159.7	24.0	107.3	67.8	8.0	1.7	0.6	3	72.1	154.7	27.9	75.9	54.2	9.3	2.0	0.7
3	78.5	141.2	25.3	102.7	70.3	8.0	1.8	0.6	4	85.3	161.6	23.7	100.9	65.6	7.6	1.7	0.7
4	86.4	164.8	28.9	113.3	70.2	7.7	1.8	0.6	5	91.6	168.1	26.0	121.9	68.0	7.6	1.6	0.7
5	90.4	184.8	25.4	98.9	66.6	7.8	1.8	0.7	6	87.5	193.5	27.4	118.8	70.0	7.9	1.8	0.6
6	73.3	145.2	24.4	92.4	66.9	7.5	1.9	0.7	8	109.2	159.4	24.2	116.1	73.3	7.0	1.7	1.0
12	91.6	134.3	25.1	125.1	67.8	8.5	1.8	0.8	12	123.0	138.5	28.4	120.6	71.7	6.8	1.6	1.0
	NS[2]	NS	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS

[1]Data are combined over 2003 and 2004 because no interactions were present at the $p \leq 0.05$ level.

[2]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 8. Tomato leaf tissue concentrations sampled at 10 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003.

Weed EST	Mineral Nutrient							Weed REM	Mineral Nutrient						
WAP	N	P	K	Ca	Mg	S	Na	WAP	N	P	K	Ca	Mg	S	Na
	%								%						
1	3.7	0.31	2.0	3.6	0.6	0.7	0.02	2	3.6	0.3	2.1	3.6	0.6	0.7	0.02
2	3.7	0.30	2.3	3.5	0.6	0.7	0.03	3	4.1	0.3	2.1	3.6	0.6	0.7	0.02
3	3.7	0.32	2.1	3.7	0.6	0.6	0.02	4	3.6	0.3	2.1	3.9	0.6	0.6	0.02
4	3.7	0.29	2.1	3.8	0.6	0.6	0.02	5	3.7	0.3	2.1	3.9	0.6	0.6	0.02
5	3.7	0.29	2.2	4.0	0.6	0.7	0.02	6	4.1	0.3	2.2	3.6	0.6	0.6	0.02
6	3.6	0.25	2.0	3.6	0.6	0.6	0.02	8	4.0	0.3	2.3	3.5	0.6	0.6	0.02
12	3.5	0.29	2.0	3.8	0.6	0.6	0.02	12	3.5	0.3	2.2	3.7	0.6	0.8	0.02
	NS[1]	0.03	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS

[1]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 8 (continued). Tomato leaf tissue concentrations sampled at 10 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003.

Weed EST	Mineral Nutrient								Weed REM	Mineral Nutrient							
WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn	WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn
	ppm									ppm							
1	40.8	139.7	36.1	745.8	99.4	5.4	1.8	0.3	2	56.8	108.7	53.3	702.3	94.7	5.8	1.8	0.7
2	50.9	157.3	42.4	728.0	90.8	5.9	1.6	0.4	3	57.8	111.9	40.8	642.8	80.7	6.2	1.9	0.8
3	45.5	122.0	58.5	703.0	91.3	5.9	1.8	0.4	4	48.1	129.0	42.1	589.0	80.9	5.9	1.8	0.5
4	48.3	144.4	37.2	687.5	89.4	6.5	1.8	0.4	5	41.8	117.6	33.0	548.0	83.2	6.2	1.8	0.5
5	53.0	138.4	36.2	662.0	85.6	5.5	1.7	0.5	6	52.5	159.4	45.0	790.5	82.6	7.1	1.9	0.4
6	63.7	181.0	55.1	680.8	79.6	6.1	1.8	0.7	8	51.4	244.5	43.6	642.3	81.6	6.5	1.7	0.4
12	45.7	90.6	42.1	807.0	93.5	5.5	1.7	0.6	12	54.2	106.8	58.4	715.3	92.9	4.8	1.6	0.6
	NS[1]	NS	NS	NS	NS	NS	NS	NS		NS	72.6	NS	NS	NS	NS	NS	NS

[1]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 9. Tomato leaf tissue concentrations sampled at 11 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003.

Weed EST	Mineral Nutrient							Weed REM	Mineral Nutrient						
WAP	N	P	K	Ca	Mg	S	Na	WAP	N	P	K	Ca	Mg	S	Na
	%								%						
1	3.2	0.3	2.3	4.2	0.7	0.6	0.03	2	3.6	0.3	2.4	4.1	0.64	0.51	0.03
2	3.5	0.3	2.6	3.9	0.7	0.5	0.03	3	3.5	0.3	2.5	4.3	0.76	0.53	0.03
3	3.4	0.3	2.4	4.4	0.7	0.4	0.03	4	3.7	0.3	2.6	4.1	0.75	0.48	0.03
4	3.7	0.3	2.4	3.8	0.6	0.6	0.03	5	3.6	0.3	2.4	4.3	0.70	0.49	0.04
5	3.5	0.3	2.6	4.3	0.8	0.6	0.03	6	3.7	0.3	2.5	3.7	0.58	0.44	0.03
6	3.6	0.3	2.5	4.1	0.7	0.5	0.03	8	3.8	0.3	2.7	3.9	0.61	0.54	0.03
12	3.4	0.3	2.4	4.6	0.7	0.5	0.04	12	3.3	0.3	2.6	4.1	0.67	0.63	0.03
	NS[1]	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	0.11	0.11	NS

[1]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.

Appendix Table 9 (continued). Tomato leaf tissue concentrations sampled at 11 weeks after planting for eastern black nightshade established (EST) or removed (REM) at various weeks after tomato planting (WAP), Fletcher, NC, 2003.

Weed EST	Mineral Nutrient								Weed REM	Mineral Nutrient							
WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn	WAP	Fe	Mn	Zn	Cu	B	N:S	N:K	Fe:Mn
	ppm									ppm							
1	43.2	149.3	36.5	1185.8	174.0	5.4	1.4	0.3	2	43.0	114.8	37.3	1134.0	157.8	7.3	1.5	0.4
2	42.6	189.3	43.5	1002.0	131.8	6.8	1.4	0.3	3	39.3	135.1	63.5	906.8	127.8	6.7	1.4	0.4
3	43.0	135.8	39.8	1234.3	159.3	6.5	1.4	0.3	4	40.9	153.1	36.5	961.5	128.8	8.2	1.5	0.3
4	42.4	140.0	38.7	1035.0	145.5	8.8	1.5	0.3	5	40.5	127.9	38.0	1010.3	145.8	7.4	1.5	0.4
5	44.7	151.2	51.0	964.8	135.0	7.0	1.4	0.3	6	51.7	168.2	35.9	1132.3	140.3	8.6	1.5	0.3
6	44.5	196.0	33.6	1085.0	135.8	7.1	1.5	0.4	8	45.4	276.1	34.0	947.8	135.3	7.5	1.4	0.3
12	40.8	103.4	37.9	1411.8	177.0	6.7	1.5	0.5	12	46.2	117.8	31.8	1032.0	157.0	5.3	1.3	0.5
	NS[1]	NS	NS	NS	NS	NS	NS	NS		NS	72.6	NS	NS	NS	NS	NS	NS

[1]Means were separated according to Fisher's protected LSD at the $p \leq 0.05$ level.