applied 16 June or 14 July 1988, while flurprimidol + mefluidide was not effective at any date.

In summary, it was necessary to repeat mefluidide or flurprimidol + mefluidide treatments at 2-week intervals, as shown in Expt. 1, to obtain effective seedhead suppression of centipedegrass throughout the summer without serious injury. Imazethapyr did not effectively suppress seedheads with two applications.

Literature Cited

Bhowmik, P.C. 1987. Response of a red fescue-Kentucky bluegrass turf to three consecutive annual applications of amidochlor, mefluidide, and ethephon. Weed Sci. 35:95-98.

Christians, N.E. 1985. Response of Kentucky bluegrass to four growth retardants. J. Amer. Soc. Hort. Sci. 110:765-769.

Demoedon, P.H. 1984. Four-year response of a Kentucky bluegrass-red fescue turf to plant growth retardants. Agron. J. 76:807-813.

DiPaola, J.M., W.B. Gilbert, and W.M. Lewis. 1985. Turfgrass response to growth retardants. Fact Sheet Fla. Turf Dig. 2(1).

Johnson, B.J. 1989a. Response of centipedegrass *(Eremochloa ophiuroides)* to plant growth regulators and frequency of mowing. Weed Technol. 3:49-53.

Johnson, B.J. 1989b. Response of tall fescue *(Festuca* arundinacea) to plant growth regulator application dates. Weed Technol. 3:408-413.

Johnson, B.J. 1988. Influence of nitrogen in the response of 'Tifway' bermudagrass (Cynodon dactylon) to flurprimidol. Weed Technol. 2:55-58.

Johnson, B.J., .R.N. Carrow, and R.E. Burns. 1988a. Centipedegrass decline and recovery as affected by fertilizer and cultural treatments. Agron. J. 80:479-486.

Johnson, B.J. and R.N. Carrow. 1988b. Frequency of fertilizer applications and centipedegrass performance. Agron. J. 80:925-929.

Kaufmann, J.E. 1985. A common sense approach to the use of PGRs. Proc. Mo. Lawn and Turf Conf. p. 69-86.

McCarty, L.B., J.M. DiPaola, W.M. Lewis, and W.B. Gilbert. 1985. Tall fescue response to plant growth retardants and fertilizer sources. Agron. J. 77:476-480.

Rogers, J.N. III, E.M. Miller, and J.W. King. 1987. Growth retardation of bermudagrass with metsulfuron methyl and sulfometuron methyl. Agron. J. 79:225-229.

SAS Institute, Inc. 1982. SAS user's guide. SAS Institute, Inc. Cary,

J. AMER. SOC. HORT. SCI. 115(3):416-422. 1990.

Evaluation of Preemergent Herbicide Phytotoxicity to Tissue, Culture-propagated 'Heritage' Red Raspberry

Joseph C. Neal[1], Marvin P. Pritts[2], and Andrew F. Senesac[3]

Cornell University, Ithaca, NY 14853

Additional index words. napropamide, oryzalin, simazine, activated carbon, herbicide safening, planting-to-treatment interval, *Rubus idaeus*

Abstract. **Five greenhouse and two Geld experiments were conducted to evaluate tissue culture-propagated (TC) raspberry (Rubus idaeus cv. Heritage) sensitivity to preemergent herbicides. Plant performance was measured by plant vigor, above-ground fresh weight, root development, and primocane number. Simazine and oryzalin caused significant injury to newly planted TC raspberry plants in greenhouse and field experiments. The severity of injury was generally linear with respect to herbicide rate, but no appreciable differences in injury were observed between the granular and spray applications. Napropamide wettable powder caused some foliar injury, but plants recovered within one growing season and growth was equal or superior to the hand-weeded controls. The granular formulation of napropamide produced similar results, but did not cause the initial foliar burn. Pre-plant dipping of roots into a slurry of activated carbon did not prevent simazine or oryzalin injury, but injury was reduced when herbicide applications were delayed. Simazine applied 4 weeks after planting was not Injurious, and oqzalin applied 2 or 4 weeks after planting caused some foliar injury, hut no reduction in plant fresh weight. Delayed treatments of napropamide increased foliar injury. Herbicide tolerance of tissue-cultured plantlets appeared to be less than that of conventionally propagated plants. Chemical names used: N,N-diethyl-2-(1-napthalenyloxy)propanamide (napropamide), 4-(dipropylamino)-3,5-dinitrobenzenesulfonamide (oryzalin), 6-chloro-N,N'diethyl-1,3,5-triazine-2,4-diamine (simazine).**

Weed control is an essential component in the management of newly planted and established raspberries. Inadequate weed control may result in reduced survival of new plantings (Lawson and Wiseman, 1976), decreased floricane and primocane numbers (Lawson and Wiseman, 1974, 1976; Stephens and Sutherland, 1962), and thinner, less-vigorous canes (Welker and Smith, 1972). Weed competition not only affects plant growth during the growing season, but may also reduce new cane numbers the following year (Lawson and Wiseman, 1976). The effects of weeds on growth and yield have also been shown to be cumulative over time (Welker and Smith, 1972). Cultivation is used to control weedy vegetation between the rows of plants, but cannot be used within the plant rows: Hand-weeding is effective, but expensive; therefore, soil residual herbicides are generally used within the plant rows to

Received for publication 12 June 1989. We thank Congdon and Weller Wholesale Nursery of North Collins. N.Y., for donating plant materials used in these experiments. We also thank Marcia Eaves-Sheavly, Maria Macksel, and Colleen Kearns for their excellent technical assistance. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[1]Assistant Professor of Weed Science. Dept. of Floriculture and Ornamental Horticulture.

[2]Assistant Professor and Small Fruit Specialist, Pomology Dept.

[3]Extension Weed Control Specialist, Cornell Univ. Long Island Horticultural Research Laboratory, Riverhead, NY 11901.

provide seasonal control of annual weeds and suppression of perennials.

Numerous soil residual herbicides have been shown to be safe when applied to established raspberries. These include simazine (Freeman, 1967; Welker and Smith, 1972), dichlobenil (Lawson et al., 1972; O'Callaghan and Rath, 1972; Welker and Smith, 1972), atrazine (Lawson et al., 1972; Freeman, 1967), terbacil (Lawson et al., 1972), and diphenamid (Welker and Smith, 1972). Atrazine, simazine, bromacil, and diuron can be used safely on newly planted, conventionally propagated rasp berries (Lawson and Wiseman, 1974). Freeman (1986) also observed that napropamide, terbacil, and simazine could be used safely on newly planted dormant canes. In the same experiment, raspberries propagated via root cuttings were more sensitive to terbacil than were dormant cane plantings, although napropamide and simazine were safe with either method of propagation.

Recent advances in micropropagation technology have made tissue-culture propagation of raspberry plants commercially feasible. Tissue-culture propagation (TC) offers several advantages over traditional methods, such as: virus-free planting stock, more rapid introduction of new cultivars, and potentially increased plant vigor (Mudge et al., 1987; Swartz et al., 1983). Unfortunately, severe injury to micropropagated brambles from lower-than-labeled rates of simazine has been observed (Mudge et al., 1987). In preliminary research (Mudge et al., 1987), micropropagated 'Royalty' raspberries were more sensitive to simazine and oryzalin than were tip-layer-propagated plants. In addition, Meador (1985) observed that oryzalin severely reduced growth of micropropagated 'Latham' red raspberry. Tissue culture-propagated plant sensitivity to soil-applied herbicides could seriously hamper the implementation of this new technology. Therefore, the objectives of these studies were 1) to determine the sensitivity of tissue culture-propagated red raspberries to several application techniques of approved preemergent herbicides and 2) to develop weed-control recommendations for tissue culture-propagated plants.

Materials and Methods

Greenhouse experiments

General methods. Tissue culture-propagated 'Heritage' raspberry plants were potted into 1.6-liter azalea pots using a 1 peat : 1 loam soil : 1 perlite (by volume) mix amended with 0.8 $kg \cdot m^{-3}$ 10N-4.4P-8.3K fertilizer, 2.4 $kg \cdot m^{-3}$ dolomitic lime, and 0.2 $kg \cdot m^{-3}$ (as 20% superphosphate). The plant materials used in each experiment were produced in vitro using the methods of Mudge et al. (1987). Basal axillary shoots were rooted in plug trays with individual plug volumes of 7 ml (288-count plug trays). Once established, the plants were transplanted into 126-count plug trays (plug volume = 24 ml), then placed in cold frames to enter natural winter dormancy. Dormant plants were brought into the greenhouse and potted after producing 5 to 10 cm of new growth. Unless otherwise noted, herbicides were applied within 24 hr of potting. Liquid applications were made with a CO_2-pressurized sprayer equipped with flat-fan nozzles and calibrated to deliver 280 $liters \cdot ha^{-1}$ using 276 kPa of pressure. Granular formulations were applied with a hand-held shaker jar. Plants were watered twice daily and a liquid fertilizer solution containing ≈ 200 ppm N (Peters 20N-8.7P-16.6K Peat-Lite Special, W.R. Grace & Co., Fogelsville Pa.) was applied weekly. A 16-hr photoperiod was maintained with HID lights providing ≈ 350 $\mu mol \cdot s^{-1} \cdot m^{-2}$ PAR at plant level. The greenhouse was maintained between 18 and 24C. Experiments were conducted in randomized complete block designs with 4 two-plant replicates, unless otherwise specified.

Herbicide phytotoxicity evaluations. Because of the large number of factors investigated, it was not possible to assess the effects of each in a single experiment; thus, simazine, oryzalin, and napropamide use on TC 'Heritage' raspberry was evaluated and compared in a series of tests. Simazine rate response was evaluated in three greenhouse tests (GH1, GH2, and GH3). The rates tested were 0.28, 0.56, and 1.1 kg a.i./ha in each test; plus 2.2 kg a.i./ha in GH1. Simazine as the 90% water-dispersible granule (90WDG) and the 4% granule (4G) were compared in GH1 and GH2. Oryzalin and napropamide were evaluated in GH3 and GH4. Oryzalin (0.48 $kg \cdot liter^{-1}$ aqueous suspension), napropamide 50% wettable powder (50WP), and napropamide 5% granule (5G) were each applied at 0.56, 1.1, and 2.2 kg a.i./ha. In GH1, plant height, plant fresh weight, and leaf area were measured 8 weeks after treatment. Since these measurements were highly correlated with each other ($r \geq 0.95$), only plant fresh weight 6 to 8 weeks after treatment was measured in subsequent experiments. In GH4, in addition to fresh weights, visual ratings of root growth were made on a scale, where 0 = no roots, 1 = minimal roots, 2 and 3 = degrees of noticeable reduction in root exploitation of the media, 4 = roots exploiting the entire root ball but ball was soft, and 5 = roots exploiting entire root ball with a firm root ball. In that same test, to assess potential foliar injury, plant quality was visually rated 2 weeks after treatment, using a modified percent vigor scale where 0 = dead plants, 5 = 50% vigor compared to the best plants, and 10 = the best growth.

Visual evaluations were analyzed both with raw data and using an arcsin transformation. No differences were observed between the two analyses; therefore, only raw data analyses are presented. Data were subjected to linear regression analysis using the PROC REG procedure (SAS, 1985). Linear regression coefficients were calculated using measured variables as dependent variables and herbicide rate as the independent variable. The herbicides and/or formulations were compared by testing for differences in their linear regression coefficients using a two-tailed *t* test (Snedecor and Cochran, 1980).

Herbicide safening. Two strategies for reducing herbicide phytotoxicity were evaluated: activated carbon root dips and delayed applications. In GH2, raspberry root plugs were dipped in a slurry containing 0.6 kg of activated carbon per liter of water. Linear regression coefficients for rate responses of dipped and non-dipped plants were compared using the two-tailed *t* test previously described.

In greenhouse test five, delayed applications of simazine and oryzalin were evaluated for potential reduction of phytotoxicity. Herbicides were applied 0, 18, and 28 days after potting. Simazine 90WDG at 0.56 and 1.1 kg a.i./ha, and oryzalin at 1.1 and 2.2 kg a.i./ha were. applied at each timing. Above-ground fresh weights were measured 9 weeks after the first treatment. Linear regression coefficients for response to application delay were compared using *t* tests to evaluate response differences to various herbicides and rates.

Field experiments

General methods. Two experiments were conducted to test herbicide phytotoxicity and methods for safening. Tissue culture-propagated 'Heritage' raspberry plants, grown in a 128-count plug tray and with » 15 cm of new growth, were used as planting stock in each test. Herbicides were applied with a CO_2

backpack sprayer Similar to the one used in greenhouse experiments.

Napropamide formulation (field test 1). Potential phytotoxicity of the 50WP and 5G formulations of napropamide were compared at 2.2 and 4.5 kg a.i./ha. Raspberries were planted on 19 May 1987 with a 0.6-m in-row spacing. The soil type was a silty clay loam (Typic Hapludalf) with a pH of ≈ 6.5. Herbicides were applied 1 week after planting in a completely random design with three replicates. Each experimental unit contained six plants. Plant quality was evaluated visually 6 weeks after treatment, using the 0 to 10 scale described previously. In Feb. 1988, all canes were cut to ≈ 4 cm from the ground, as required for fall-bearing management. In Mar. 1988, all plots were sprayed with 1.1 kg a.i./ha of simazine plus 4.5 kg a.i./ha of oryzalin as a maintenance treatment. Primocane numbers per plot for the 1988 season were counted on 12 Aug. 1988. Data were subjected to analysis of variance (ANOVA) to test for rate, formulation, and interaction effects. Values for the untreated control were deleted for analysis of rate and formulation effects. A Bayesian least significant difference value, PROC MEANS VAR/WALLER (SAS, 1985), was used to compare individual treatments to the untreated plots. A single degree of freedom comparison, CONTRAST (SAS, 1985), was used to compare a pooled napropamide value to the untreated.

Root dips and delayed herbicide application (field test 2). Based on the results from greenhouse tests, this experiment was designed to further evaluate activated carbon root dips and delayed herbicide applications. For root-dip evaluations, root plugs were dipped in an activated carbon plus water slurry containing 0.3 kg activated carbon/liter before being planted on 14 May 1987. Plants were spaced 0.6 m in-row and 1.5 m between rows. Soil type was a Riverhead sandy loam (mixed Mesic Typic Dystrochrept) with a pH of 5.6. The herbicide treatments were simazine 90WDG at 1.1 and 2.2 kg a.i./ha, oryzalin at 2.2 and 4.5 kg a.i./ha, and napropamide 50WP at 2.2 and 4.5 kg a.i./ha. Each herbicide treatment was applied at planting, or 2 or 4 weeks after, planting (0 WAP, 2 WAP, and 4 WAP, respectively). The experimental design was a randomized complete block with 4 five-plant replicates. Herbicide phytotoxicity was visually evaluated on 19 June and 30 July 1987 using the 0 to 10 scale described previously. On 10 Feb. 1988, all canes were cut to ≈ 2.5 cm, ‘as required for management of fall-bearing raspberries. Herbicide treatments were reapplied on 27 Apr. 1988. Phytotoxicity was reevaluated on 20 May 1988. On 23 Aug. 1988 (16 months after initial treatments), all plants were severed at the ground level; canes were counted and weighed. Data for root dip vs. no root dip, and planting-to-treatment interval comparisons were analyzed separately. The root dip vs. no root dip comparison data were subjected to ANOVA with herbicide, rate, and root dip as the main effects. To test the effect of delayed herbicide applications, data were subjected to regression analysis, and regression coefficients for herbicides and rates were compared using *t* tests as described previously.

Results

Greenhouse experiments

Herbicide phytotoxicity. Simazine and oxyzalin injury were each linear with respect to herbicide rate. Regression coefficients for simazine were between - 11.7 and -40.9 g fresh weight·(kg a.i./ha)$^{-1}$ for above-ground fresh weight (Table 1). No significant differences in phytotoxicity were observed between the granular (4G) and sprayable (90WDG) formulations of simazine, which suggests that plant injury was related to root uptake, not foliar injury. Regression coefficients for oryzalin were - 11.5 and - 13.3 for fresh weights in experiments GH3 and GH4. respectively. Napropamide did not reduce raspberry fresh weight or root growth. While some foliar injury from the napropamide 50WP formulation appeared to be present 2 weeks after treatment, the differences were nonsignificant (data not presented). No difference in formulations was observed, except with root ratings, where the 5G formulation slightly enhanced root growth (Table 1). Based on *t* test comparisons, simazine was more phytotoxic than oryzalin (Table 1).

Table 1. Linear regression analysis of simazine, oryzalin, and napropamide rate effects on tissue-cultured ‘Heritage’ raspberry plants in greenhouse experiments.

	Linear regression coefficients and associated significance levels (*P*), by experiment[z]									
	GH1 (fresh wt)		GH2 (fresh wt)		GH3 (fresh wt)		GH4 (fresh wt)		GH4 Root[y]	
Herbicide	coeff.	*P*	coeff.	*P*	coeff.	*P*	coeff.	*P*	coeff.	*P*
Simazine 90WDG	−11.8	0.01	−33.9	0.001	−24.1	0.001				
Simazine 4G	−11.7	0.02	−40.9	0.002						
Oryzalin					−11.5	0.004	−13.3	0.08	−0.8	0.08
Napropamide 50WP					−2.0	NS	−0.4	NS	+0.2	NS
Napropamide 5G							+1.8	NS	+0.4	NS
Comparisons[x]										
Simazine formulation	NS		NS							
Napropamide formulation							NS		0.05	
Simazine vs. oryzalin					0.001					
Simazine vs. napropamide					0.001					
Oryzalin vs. napropamide					0.001		0.001		0.001	

[z]Analysis of above-ground fresh weight data. GH1, GH2, GH3, and GH4 denote greenhouse tests 1, 2, 3, and 4, respectively. Units are g fresh weight·(kg a.i./ha)$^{-1}$.
[y]Analysis of visual ratings of root growth using a scale where 0 = no roots and 5 = firm root ball filling the pot.
[x]Two-tailed *t* test comparisons of regression coefficients. For chemical comparisons, both formulations of simazine and napropamide produced the same significance levels; thus, formulations were dropped from this presentation.

Herbicide safening. While activated carbon root dips provided some protection against simazine injury (P = 0.001), root-dipped plants were still significantly injured. Regression coefficients for nondipped and dipped plants treated with simazine 90WDG were -33.9 and -22.1, respectively. These slope values were significant at the 0.001 and 0.006 levels, respectively. Results for the 4G formulation were similar, with regression coefficients for nondipped and dipped of - 40.9 and - 20.8, significant at the 0.002 and 0.09 levels, respectively. These data suggested that activated carbon could provide protection against low rates (≤ 0.56 kg a.i./ha) of simazine, but not against higher rates. Ahrens (1965) observed similar results with woody species he classified as very sensitive to simazine.

Increasing the potting-to-treatment interval from 0 to 28 days improved the ability of TC raspberry plants to tolerate simazine and oryzalin (Fig. 1). Oryzalin applied at potting caused injury at both rates, with the higher rate causing greater injury (P = 0.05) and some plant death. By 18 days after potting (DAP), plants were tolerant of oryzalin. Some foliar injury was observed (data not presented), but no reduction in plant fresh weight resulted. The linear regression coefficients for both rates of oryzalin were highly significant (Table 2). Since fresh weight values for the two rates of oryzalin applied at potting were significantly different (P = 0.05), and the 18 DAP and 28 DAP values were similar, regression coefficients for the two rates were significantly different (Table 2).

When applied at potting, simazine caused severe injury at 0.56 kg a.i./ha and killed most plants at 1.1 kg a.i./ha (Fig. 1). For both rates there was a linear improvement in plant tolerance over the potting-to-treatment intervals tested (Table 2). Regression coefficients for the two rates were similar, indicating that the interval required to ensure protection against injury will increase as the simazine rate increases.

Field experiments

Napropamide formulation. Visual evaluations 6 weeks after treatment revealed a significant increase in plant growth with napropamide at 2.2 and 4.5 kg a.i./ha, as compared to hand-weeded plots (Table 3). There were no rate or formulation effects.

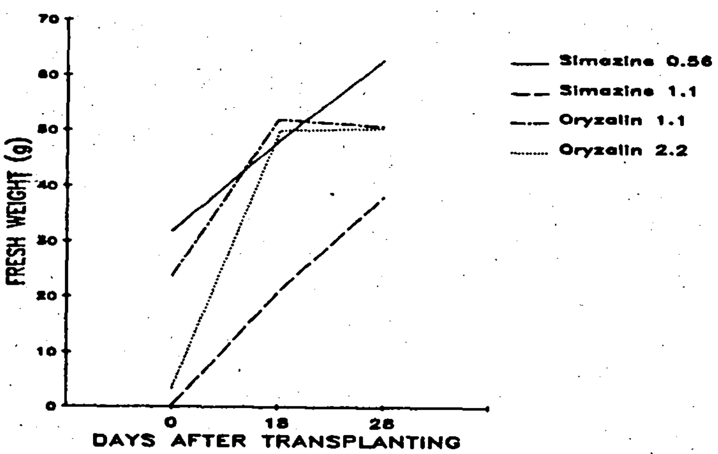

Fig. 1. Influence of delaying herbicide applications on tissue-cultured 'Heritage' raspberry fresh weight—greenhouse test 5. Herbicides were applied 0, 18, or 28 days after transplanting. Above-ground fresh weights were measured 9 weeks after potting. Application rates are expressed in kg a.i./ha. See Table 2 for results of the linear regression analysis.

Table 2. Regression analysis of the influence of potting-to-treatment intervals on simazine and oryzalin phytotoxicity to tissue-cultured 'Heritage' raspberry–greenhouse test 5.

Herbicide	Rate (kg a.i./ha)	Regression coefficient[z] (g fresh wt/day delay)	P^y
Simazine	0.56	+ 1.1	0.009
	1.1	+ 1.3	0.002
Oryzalin	1.1	+ 1.0	0.008
	2.2	+ 1.7	0.001
t test comparisons of regression coefficients			
Simazine 0.56 vs. simazine 1.1			NS
Oryzalin 1.1 vs. oryzalin 2.2			0.001
Simazine 0.56 vs. oryzalin 1.1			NS
Simazine 1.1 vs. oryzalin 2.2			0.07

[z]Linear regression coefficient for interval response.
[y]Probability values for significance of associated regression coefficients or comparisons.
[NS]Not significant at P = 0.1.

Table 3. A comparison of napropamide formulations for phytotoxicity to field-planted tissue-cultured 'Heritage' raspberry plants–field test 1.

Herbicide	Rate (kg a.i./ha)	Visual rating[z] 6 WAT	Primocane 15 MAT[y] (no./plot)
None (hand-hoed)	---	8.0	164
Napropamide 50WP	2.2	9.7	261
50WP	4.5	9.7	301
5G	2.2	10.0	283
5G	4.5	10.0	336
LSD (0.05)		1.0	217
Main effects and interactions[x]			
Napropamide rate		NS	NS
Napropamide formulation		NS	NS
Napropamide rate by formulation		NS	NS
Napropamide vs. hand-weeded		0.05	0.1

[z]Visual ratings obtained 6 weeks after treatment (6 WAT) using a scale where 10 = the best possible growth and 0 = dead plants.
[y]Primocane numbers per plot were measured 15 months after initial treatments (15 MAT). Plot size was 3.7 m^2.
[x]Significance levels for main effects, interactions, and single degree of freedom contrasts are designated by the associated probability value or NS where nonsignificant at P = 0.1.

The effect of 1987 treatments on 1988 primocane numbers was evaluated 15 months after planting. Data were highly variable and no significant differences were identified between napropamide rates or formulations. A single degree of freedom comparison between the pooled napropamide treatments and the hand-weeded treatment indicated a slight increase in primocane numbers in napropamide-treated plots (P = 0.1).

Root dips and delayed herbicide application. Activated carbon root dips reduced simazine and oryzalin injury (Table 4). Evaluations 6 weeks after treatment indicated protectant action that produced plant growth equal to untreated plants. However, 12 months after treatment, plant growth in simazine and oryzalin treatments, with or without root dips, was less than that observed in the hand-weeded treatment (Table 4). These observations were consistent with results obtained in greenhouse test 2, where activated carbon root dips did not prevent injury from simazine applied at labeled rates. Activated carbon root dips had no significant effect on napropamide safety.

Plants treated with napropamide produced growth equal to,

Table 4. Influence of activated carbon root dips (RD) on herbicide phytotoxicity to tissue-cultured 'Heritage' raspberries evaluated 6 weeks after treatment (6 WAT), 12 months after treatment (MAT), and 16 MAT.

Herbicide	Rate (kg a.i./ha)	Visual rating 6 WAT[z]		Visual rating 12 MAT[z]		Fresh wt (kg) 16 MAT[y]		Primocane no. 16 MAT[y]	
		+RD[x]	−RD	+RD	−RD	+RD	−RD	+RD	−RD
None (hand-weeded)		7	6	8.3	8.5	3.7	3.3	108	101
Napropamide	2.2	8	8	8.5	8.3	4.7	3.8	136	109
	4.5	9	9	8.5	8.8	5.1	6.0	134	189
Simazine	1.1	8	5	6.8	7.6	4.6	3.8	116	112
	2.2	6	4	6.5	6.8	4.3	4.3	102	98
Oryzalin	2.2	7	7	6.8	6.0	4.9	3.8	96	106
	4.5	8	4	5.0	5.8	4.4	2.6	107	72
LSD[w] (0.05)		2		1.6		2.8		92	
ANOVA, +RD vs. −RD									
Napropamide		NS		NS		NS		NS	
Simazine		0.03		NS		NS		NS	
Oryzalin		0.03		NS		0.001		NS	

[z]Plants were visually evaluated on a scale where 0 = dead plants and 10 = best possible growth.
[y]Fresh weight and primocane number are expressed on a per-plot basis. Plot size was 3.7 m^2.
[x]+RD, -RD; designate the presence or absence *of* a pre-plant activated carbon root dip containing 0.3 kg activated carbon/liter.
[w]Bayesian least significant difference value *for* mean comparisons within and between columns.

or better than, the untreated, hand-weeded plants (see non-root-dip data, Table 4). Simazine at 2.2 kg a.i./ha and oryzalin at 4.5 kg a.i./ha caused significant injury, measured 6 weeks and 12 months after treatment (Table 4). Plants recovered by 16 months after treatment, as simazine and oryzalin injury was no longer significant compared to the hand-weeded treatment. However, primocane number and fresh weight were less for oryzalin than for napropamide at 4.5 kg a.i./ha, the most vigorous treatment.

Planting-to-treatment interval evaluations produced results similar to those observed in the greenhouse. Visual ratings 6 weeks after the first treatment (6 WAT) showed positive linear responses for oryzalin and simazine, indicating that delayed applications, 2 or 4 WAP, were safer than at-plant treatments (0 WAP) (Table 5). When evaluated 12 months after the first treatment (12 MAT), interval effects were nonlinear for simazine, but linear for oryzalin. Intervals had no effect on napropamide safety evaluated 6 WAT; however, by 12 MAT, negative regression coefficients indicated that delayed treatments increased plant injury (Table 5).

Sixteen months after treatment, plants had recovered from much of the herbicide injury observed in the first season (Table 6). While data still showed .a trend toward a positive interval response for simazine, the differences were nonsignificant. The response to delayed 'application of oryzalin was significantly positive and linear for plant fresh weight, but nonlinear for primocane number. Comparisons of regression coefficients for each herbicide showed that interval responses for simazine and oryzalin were similar, and that each was different from napropamide. Extending the planting-to-treatment interval for napropamide resulted in a marginally significant *(P* = 0.09) decrease in primocane numbers.

Discussion

Simazine and oryzalin caused significant injury to TC 'Heritage' raspberry plants in greenhouse and field experiments. In general, injury was more severe in greenhouse tests, but the trends were similar between growing sites. Lawson and Wiseman (1974) and Freeman (1986) reported no injury to traditionally propagated red raspberries from similar rates of simazine. However, in a preliminary experiment, we observed that, micropropagated 'Royalty' raspberries were more sensitive to simazine and oryzalin than were tip layer-propagated plants (Mudge et al., 1987). Meador (1985) also observed similar injury from oryzalin applications to newly planted TC 'Latham' raspberries.

Activated-carbon root dips provided insufficient protection against herbicide injury. Ahrens (1965) reported that the degree of protection afforded by activated-carbon root dips depended upon simazine rate and the level of injury in unprotected plants. In that research, as in ours, very sensitive plants could not adequately be protected against simazine injury in this manner. Simazine and oryzalin applications were safened by delaying treatments 4 weeks after planting. However, under grower conditions, a 4-week delay in preemergent herbicide applications would require supplemental cultivation and hand-weeding for removal of established weeds.

Meador (1985) observed slight injury to TC 'Latham' raspberries from napropamide in early ratings, but, by 3 months after treatment, plant growth was equal to controls. In our tests, at-planting applications of napropamide 50WP caused some foliar injury to TC raspberry plants, but all plants recovered and produced above-ground fresh weights equal to or greater than the untreated, hand-weeded plants. As all plots were maintained weed-free by supplemental hoeing, treatment differences were not likely attributed to differences in weed control or soil disturbance, although untreated plots probably required more (or more frequent) supplemental hoeing. Rather, it appears that napropamide has a positive influence on plant growth under certain conditions. Further research should be conducted to determine reasons for enhanced growth of napropamide-treated plants and why delayed applications of napropamide resulted in plant injury that was detectable up to 16 months later.

Analyses of the planting-to-treatment interval effects on plant growth and quality showed varying effects over time and between evaluation methods. However, delayed treatments of simazine and oryzalin were consistently safer than at-planting applications, but delayed treatments of napropamide were more injurious than at-planting applications. These effects were ob-

Table 5. Effect of planting-to-treatment intervals on visual growth and visual quality ratings of tissue-cultured 'Heritage' raspberries 6 weeks after first treatment (6 WAT) and 12 months after treatment (12 MAT).

Herbicide	Rate (kg a.i./ha)	Visual rating 6 WAT[z,y]			Regression analysis[x]			
					6 WAT		12 MAT	
		0 WAP	2 WAP	4 WAP	Reg. coeff. ($kg\cdot week^{-1}$)	*P*	Reg. coeff. ($kg\cdot week^{-1}$)	*P*
Napropamide	2.2	8	8	8	0	NS	0.1	NS
	4.5	9	7	8	−0.3	NS	−0.6	0.07
Simazine	1.1	5	8	8	0.5	0.06	0.3	NS
	2.2	7	8	7	0.2	NS	0.3	NS
Oryzalin	2.2	7	8	7	0.2	NS	0.5	0.06
	4.5	4	8	8	1.1	0.03	0.7	0.09
t test comparisons with probability values								
Napropamide vs. simazine					0.001		0.001	
Napropamide vs. oryzalin					0.001		0.001	
Simazine vs. oryzalin					NS		0.10	

[z]Six WAT–visual ratings, 6 weeks after the first treatment, using a scale where 10 = best possible growth and 0 = dead plants. Mean value for untreated plants was 6.0. LSD (0.05) for mean comparisons = 2.
[y]0 WAP, 2 WAP, 4 WAP designate treatment 0, 2, or 4 weeks after planting.
[x]Linear regression analyses for visual ratings 6 WAT and 12 MAT with regression coefficients and associated significance levels *(P)*. NS = nonsignificant at *P* = 0.1.

Table 6; Effect of planting-to-treatment intervals on above-ground fresh weight and primocane number for tissue-cultured 'Heritage' raspberry 16 months after planting.

Herbicide	Rate (kg a.i./ha)	Fresh wt (kg)[z]			Regression analysis[y]			
					Fresh wt		Primocane no.	
		0 WAP	2 WAP	4 WAP	Reg. coeff. ($kg\cdot week^{-1}$)	*P*	Reg. coeff. (No./week)	*P*
Napropamide	2.2	3.8	5.2	4.9	0.3	NS	7.5	NS
	4.5	6.0	4.1	4.3	−0.4	NS	−16.5	0.09
Simazine	1.1	3.8	4.7	5.2	0.4	NS	2.8	NS
	2.2	4.3	5.8	5.8	0.4	NS	9.2	NS
Oryzalin	2.2	3.8	4.0	4.8	0.2	0.07	6.1	NS
	4.5	2.6	4.4	4.5	0.5	0.03	8.9	NS
t test comparisons with probability values								
Napropamide vs. simazine					0.001		0.001	
Napropamide vs. oryzalin					0.001		0.001	
Simazine vs. oryzalin					NS		NS	

[z]0 WAP, 2 WAP, and 4 WAP designate treatment 0, 2, or 4 weeks after planting. Average fresh weight for untreated plots was 3.3 kg. LSD (0.05) for mean comparisons = 2.8.
yLinear regression analysis of delayed treatment effects on above-ground fresh weight and primocane number with regression coefficients and associated significance levels. NS = nonsignificant at *P* = 0.1.

served up to 16 months after planting. As certain data indicated linear interval responses for simazine and oryzalin, planting-to-treatment intervals of 4 WAP would be beneficial as compared to shorter intervals.

The results of these experiments clearly showed that simazine and oryzalin, applied at planting, were injurious to TC 'Heritage' raspberries. Napropamide was safe for A-planting treatments; however, to improve the spectrum of weeds controlled, simazine or oryzalin could be safely applied 4 WAP.

Literature Cited

Ahrens, J.F. 1965. Improving herbicide selectivity in horticultural crops with activated carbon. Proc. Northeastern Weed Control Conf, 19:366-367.

Freeman, J.A. 1967. Effects of applying paraquat, atrazine and simazine for weed control in raspberries in coastal British Columbia. Can. J. Plant Sci. 47:25-31.

Freeman, J.A. 1986. Chemical weed control in newly planted raspberries in coastal British Columbia. Can. J. Plant Sci. 66:141-152.

Lawson, H.M. and J.S. Wiseman. 1974. Effect of weeds and herbicides in young raspberry plantations. Proc. 12th Brit. Weed Control Conf. 12:683-690.

Lawson, H.M. and J.S. Wiseman. 1976. Weed competition in spring-planted raspberries. Weed Res. 16:155-162.

Lawson, H.M., J.S. Wiseman, and P.D. Waister. 1972. Tolerance of established raspberry plantations IO a range of residual herbicide treatments. Proc. 11th Brit. Weed Control Conf. 11:430-436.

Meador, D.B. 1985. Impact of herbicides on field planted succulent, tissue-culture propagated red raspberry plants. HortScience 20:48. (Abstr.)

Mudge, K.W., C.A. Borgman, J.C. Neal, and H.A. Weller. 1987. Present limitations and future prospects for commercial micropropagation of small fruits. Proc. Intl. Plant Prop. Soc. 36:538-543.

O'Callaghan, T.F. and N. Rath. 1972. The effect of repeated applications of chlorthiamid and dichlobenil on blackcurrants and raspberries. Proc. 11th Brit. Weed Control Conf. 11:437-443.

SAS Institute Inc. 1985. SAS user's guide: Statistics, Version 5 Edition. SAS, Cary, N.C.

Snedecor, G.W. and W.G. Cochran. 1980. Statistical methods. 7th ed. The Iowa State Univ. Press, Ames.

Stephens, R.J. and J.P. Sutherland. 1962. Effects of some herbicides on the weeds and crop in a raspberry cane nursery. Hort. Res. 1:112-119.

Swartz, H.J., G.J. Galletta, and R.H. Zimmerman. 1983. Field performance and phenotypic stability of tissue culture-propagated thornless blackberries. J. Amer. Soc. Hort. Sci. 108:285-290.

Welker, W.V., Jr., and C.R. Smith. 1972. Effect of repeated annual applications of herbicides in red raspberry plantings. Weed Sci. 20:423-433.

J. Amer. Soc. Hort. Sci. 115(3):422-426. 1990.

Foliar-applied Iron Enhances Bermudagrass Tolerance to Herbicides

Billy J. Johnson[1], Robert N. Carrow[2], and Tim R. Murphy[3]

Department of Agronomy, University of Georgia, Georgia Station, Griffin, GA 30223-1797

Additional index words. *Cynodon dactylon* × *C. transvaalensis*, turf injury, turf quality, turf color

Abstract. **Field experiments were conducted to determine the effects of foliar iron (Fe) applied with postemergence herbicides on injury, color, and quality of 'Tifway' bermudagrass *[Cynodon transvaalensis* Burtt-Davy × *Cynodon dactylon* (L.) Pers.]. Iron significantly decreased injury and improved quality and color of 'Tifway' bermudagrass in conjunction with herbicide treatment. Turf injury was less for 4 to 18 days after the initial MSMA application when Fe was added. Injury was also less from sequential Fe treatment with MSMA + metribuzin (up to 4 days) and MSMA + imazaquin (from 4 to 10 days) compared to the respective herbicides applied alone. There was no difference in turf injury from Fe when imazaquin at 1.3 kg·ha^{-1} was applied as a single treatment. However, turf treated with Fe and two applications of imazaquin (9- to 10-day interval) recovered from herbicide injury faster than when treated only with the herbicide. Iron did not prevent immediate 2,4-D + mecoprop + dicamba injury to the bermudagrass, but did hasten turf recovery from injury at 26 days after treatment. With a few exceptions, 'Tifway' bermudagrass quality was higher and color improved when Fe was added. However, injury expressed as loss of shoot density was not affected by Fe and only injury expressed as color loss was improved by Fe. Chemical names used: 3,6-dichloro-2-methoxybenzoic acid (dicamba), 2-[4,5-dihydro-4-methyl)-4-(1-methylethyl)-5-oxo-1H-imidazol-2yl]-3-quinolinecarboxylic acid (imazaquin), (±)-2-(4-chloro-2-methylphenoxy)propanoic acid (mecoprop), 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one (metribuzin), monosodium salt of MAA (MSMA), and (2,4-dichlorophenoxy)acetic acid (2,4-D).**

Postemergence herbicides are necessary to control emerged weeds in bermudagrass turf. For example, MSMA (Johnson, 1975) has been used for control of large crabgrass *(Digitaria sanguinalis* L. Scop.), MSMA + metribuzin (Johnson, 1980) for goosegrass *(Eleusine indica* L. Gaertn.) imazaquin or MSMA + imazaquin (Coats et al., 1987) for purple nutsedge *(Cyperus rotundus* L.), and 2,4-D + mecoprop + dicamba for various broadleaf weeds (Johnson, 1987). Although these herbicides are labeled for bermudagrass, various degrees of turf injury usually occur within a few days following herbicide application. Injury may be expressed as loss of shoot density and/or discoloration. Slight to moderate discoloration of bermudagrass occurred when treated with MSMA (Johnson, 1981) or imazaquin (Coats et al., 1987), while severe injury was reported when the grass was treated with MSMA + metribuzin (Johnson, 1980) or 2,4-D + mecoprop + dicamba (Johnson, 1978, 1983). However, bermudagrass fully recovered within 2 to 4 weeks after herbicide treatments regardless of the amount of initial injury.

Received for publication 30 Jan. 1989. Supported by state and Hatch Act funds allocated to the Georgia Agricultural Experiment Stations. We thank Jerry Davis, station statistician, for his cooperation in these studies. We also gratefully acknowledge R. Waites and T. Dinkins for technical assistance. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[1]Professor
[2]Associate Professor,
[3]Assistant Professor.

When selecting herbicides for weed control, it is desirable to use chemicals in conjunction with a management system that causes the least amount of injury to the desired turf. This is especially true on turf sites where high quality is expected. In an earlier study, bermudagrass injury from postemergence herbicides was masked or reduced by nitrogen treatments (Johnson, 1984). Several researchers have reported that foliar-applied Fe improves the color and quality of creeping bentgrass *(Agrostis palustrus* Huds.) (Schmidt and Snyder, 1984; Snyder and Schmidt, 1974); Kentucky bluegrass *(Poa pratensis* L.) (Yust et al. 1984), and centipedegrass *[Eremochloa ophiuroides* (Munro.) Hack.] (Carrow et al., 1988). Snyder and Schmidt (1974) suggested that frequent Fe treatments may offset the effects of adverse environmental conditions. However, we found no research data on the possible effects of Fe on herbicide injury to bermudagrass. In addition, the response of turfgrasses to Fe varies with application rates (Horst, 1984), turfgrass species (Beard, 1973), temperature, and rate of turf growth (Carrow et al. 1988; Schmidt and Snyder, 1984).

Since postemergence herbicides temporarily discolor bermudagrass and Fe improves greenness, experiments were conducted on bermudagrass to determine if Fe applied with postemergence herbicides would prevent or reduce turf injury.

Materials and Methods

Two experiments were conducted on 'Tifway' bermudagrass maintained at a mowing height of 2 to 3 cm at Griffin, Ga. during 1988. The grass was mowed with a reel mower three