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Efficacy of Triapenthenol as a Safener Against Metribuzin Injury in Soybean (*Glycine max*) Cultivars

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Abstract. Triapenthenol or RSW 0411 (*B*(-cyclohexalmethylene)-gamma-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol), a triazole plant growth regulator, applied preemergence as a separate broadcast application, protected tolerant and midtolerant soybean cultivars from metribuzin (4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one)-induced necrotic injury, and stabilized seedling fresh weight and dry weight loss to herbicide treatment. Soybean yields were not significantly reduced by triapenthenol treatment alone, but 1.12 kg ai/ha metribuzin and a 0.56 kg ai/ha triapenthenol plus 1.12 kg ai/ha metribuzin combination reduced crop yield averaged across cultivars.

In 1984, metribuzin was used on 49.4% of the soybean acreage in Georgia (French 1984). Soybean cultivar tolerance to metribuzin, however, is quite variable (Wax et al. 1976, Barrentine et al. 1976, Hardcastle 1979), and extensive herbicide injury may occur from metribuzin application in some cultivars. Genetically defined inheritance of tolerance (Souza-Machado et al. 1982) or susceptibility (Edwards et al. 1976) to metribuzin appears to reside in detoxification and/or immobilization of the herbicide moiety (Smith and Wilkinson 1974) before it reaches the chloroplast (Souza-Machado and Ditto 1982).

Potato (*Solanum tuberosum* L.) also exhibits a cultivar response to metribuzin. Phatak et al. (1985) showed daminozide (butanedioic acid mono-(2,2-dimethylhydrazide)) applied foliarly 14 days prior to metribuzin application safened potato against metribuzin injury. Concomitant with reduced injury, a significant increase in potato total soluble solids was noted. Frear et al. (1983) had previously established N-glucoside/metribuzin conjugations as a major route of detoxification in tomato. Glucoside conjugation in soybean is a detoxification

route; however, a homoglutathione conjugation is proposed to be the major route (Frear et al. 1985).

Preliminary work in tomato (*Lycopersicon esculentum* Mill.) (unpublished) and soybean (Vavrina and Phatak 1985, 1986a,b, Vavrina 1986) indicate a variety of PGRs may offer metribuzin safening. Plant growth regulation may also figure in safening from other photosynthetic inhibitors (Vavrina and Phatak 1986b).

The purpose of this research was to define the role of triapenthenol as a safener against metribuzin injury across the three genetically defined divisions of soybean cultivar tolerance to metribuzin.

Materials and Methods

Experiments were conducted at two locations on similar soil types in Tift County, Tifton, Georgia in 1985. The soil at location 1 was a Tifton very fine sandy loam (siliceous thermic Plinthic Paleudults), and that of location 2 was a Tifton sandy loam. The pH at both sites was adjusted to 6.0 by broadcast application of lime. Planting dates for the two soils were May 21 and June 24, respectively. The soybean cultivars used in the study were Essex (tolerant), Braxton (tolerant), Delta Pine 105 (midtolerant), Centennial (midtolerant), and Semmes (susceptible) (personal communication, Dr. Richard Rudolph, Mobay Chemical Company 1985).

Four treatments were applied preemergence to each cultivar: untreated control, triapenthenol at 0.56 kg ai/ha, metribuzin at 1.12 kg ai/ha, and a triapenthenol plus metribuzin sequentially applied treatment at the same respective rates. Land preparation consisted of conventional tillage. Prior to the experimental treatments, a three-way tank-mix preplant soil incorporated (via rotovator) broadcast application of the following treatments was made: 0.56 kg ai/ha trifluralin (2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine) plus 2.24 kg ai/ha metolachlor (2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide) plus 3.36 kg ai/ha fenamiphos (ethyl 3-methyl-4-(methylthio)-phenyl-(1-methylethyl) phosphoramidate). Five hundred sixty kilograms per hectare of a 10-10-10 fertilizer was banded 10 cm below and to the side of the soybean rows. Soybeans were planted at a rate of 16 seeds per meter of row with a Stanhay precision seeder to plots consisting of four rows, 45-cm between-row spacing, 12.2 m in length. The metribuzin and triapenthenol treatments were applied separately, and each application was followed by 0.6 cm of sprinkler irrigation.

Data taken during the study included visual injury ratings (as % stand necrosis) 14 and 21 days after planting (DAP); based on 1 m of row plant population at emergence, 30 and 60 DAP, plant fresh weight (FW) and dry weight (DW) 30 and 60 DAP; and soybean yield based on 6.1 m of row. The experiments were designed as a split-split plot factorial with date, triapenthenol and metribuzin as the main plots, and soybean cultivars as the subplots. The treatments were repeated four times.

Table 1. Mean-square values and level of significance for the sources of the variation after analysis of variance.[a]

Variance source	Injury		Population							
	1	2	1	2	3	3–1	FW1	DW1	FW2	DW2
D	0.6	17480**	12	29*	5	32	188**	14**	14**	142*
Rp (D)	1023**	805**	3	15*	9	16	95**	0	3	85**
T	25923**	5655**	0	37*	3	3	16	0	1	19
M	74300**	68328**	0	328**	290**	268**	1129**	30**	3	8
T*M	20233**	5229**	3	5	0	1	489**	12**	4	205**
C	5481**	6906**	697**	910**	656**	6	181**	1*	10**	182**
T*C	1173**	301*	2	6	6	13	6	0	1	70*
M*C	5858**	7007**	2	20**	34**	40*	17	0	3	51
T*M*C	916**	336*	1	3	6	5	6	0	1	73*
D*T	69	2852**	0	29*	0	0	175**	2*	12**	376**
D*M	382	17100**	1	27*	35	45	122**	0	2	21
D*T*M	109	3008**	3	3	11	3	17	0	11**	246**
D*C	137	919**	30**	32**	40**	15	22	1*	2	17
D*T*M*C	142	490**	4	5	9	11	8	0	9**	54*
Error	271	132	3	6	10	14	10	0.4	1.4	26

[a] Injury 1, 2 = 14 and 21 (DAP), respectively. Population 1, 2, 3 = at emergence, 30 DAP, and 60 DAP, respectively. FW and DW 1, 2 = fresh and dry weight 30 DAP and 60 DAP, respectively. T = triapenthenol; M = metribuzin; D = date; C = cultivar; Rp = replication.
** Significance at $p = 0.01$.
* Significance at $p = 0.05$.

Results

The mean squared values for the components of the factorial design are presented in Table 1. Mean values for the various parameters of the study are presented in Table 2.

Planting Date

Soybeans planted on June 24, 1985, tended to have significantly less metribuzin-induced visual injury 21 DAP and greater plant FW and DW at both 30 and 60 DAP than soybeans planted on May 21. The increased vigor exemplified by the June- vs. the May-planted soybeans probably accounted for the reduced injury 21 DAP and better seedling survival 30 DAP across treatments also.

Triapenthenol Effect

The application of triapenthenol at 0.56 kg ai/ha alone caused no visual injury (necrosis) to soybean cultivars but reduced plant height and increased chlorophyll content as previously reported (Vavrina and Phatak 1985, Vavrina 1986).

Table 2. The effect of triapenthenol, metribuzin, and triapenthenol plus metribuzin on the growth of soybeans during the first 60 days of development.[a]

			Necrosis		Population							
Cultivar	T	M	1	2	1	2	3	FW1	DW1	FW2	DW2	Yield
	(kg/ha)		- (%) -		----- (#) -----			---------- (g) ----------				(kg/ha)
Planted 5/21/85												
Essex	0	0	0	0	15	14	15	14.6	1.99	39.6	9.11	1866
	0.56	0	0	0	15	14	15	8.2	1.44	34.8	7.75	1487
	0	1.12	53	58	15	11	13	4.0	0.69	50.9	13.28	1049
	0.56	1.12	4	21	16	11	14	10.4	1.88	34.3	7.48	1312
Braxton	0	0	0	0	15	16	14	14.1	1.93	50.8	12.35	3033
	0.56	0	0	0	14	16	15	7.4	1.32	30.4	7.08	2654
	0	1.12	45	64	15	13	15	3.3	0.50	38.1	9.06	2420
	0.56	1.12	0	13	14	14	13	4.9	0.85	30.7	6.97	2333
Centennial	0	0	0	0	23	21	22	10.1	1.49	27.2	7.16	2187
	0.56	0	0	0	20	22	20	6.5	1.17	24.8	6.00	2274
	0	1.12	64	79	18	13	13	2.2	0.41	35.9	8.01	1166
	0.56	1.12	3	19	22	20	15	5.6	0.86	27.8	5.56	1983
DPL 105	0	0	0	0	15	14	16	14.3	2.00	34.1	8.87	2187
	0.56	0	0	0	15	15	14	10.8	1.62	33.0	7.83	1983
	0	1.12	59	73	14	12	11	3.1	0.96	39.9	9.09	1924
	0.56	1.12	17	59	15	14	13	2.9	0.53	31.9	7.16	1283
Semmes	0	0	0	0	8	7	8	11.3	1.73	43.1	9.64	1662
	0.56	0	0	0	8	8	10	7.5	1.27	31.9	7.09	1424
	0	1.12	93	97	9	1	5	2.4	0.21	146	16.58	554
	0.56	1.12	93	96	10	2	3	3.4	0.39	67.0	13.28	729
LSD[5]%			23	23	2	4	5	4.8	0.8	N.S.	6.7	580
Planted 6/24/85												
Essex	0	0	0	0	15	15	15	9.8	1.79	53.8	11.16	1755
	0.56	0	0	0	15	17	14	11.4	1.94	57.5	11.79	1919
	0	1.12	45	7	15	14	13	5.5	0.97	37.4	7.98	979
	0.56	1.12	2	0	16	15	13	11.0	1.90	67.5	14.14	1306
Braxton	0	0	0	0	15	16	14	11.2	2.10	63.6	12.01	2970
	0.56	0	0	0	15	14	14	10.2	1.87	50.6	8.83	2654
	0	1.12	40	5	15	14	13	5.9	1.08	37.6	6.80	2409
	0.56	1.12	2	0	15	13	15	8.6	1.74	58.6	9.64	2735
Centennial	0	0	0	0	22	24	23	7.6	1.37	36.6	7.27	2082
	0.56	0	0	0	23	23	21	7.7	1.40	36.6	6.56	2572
	0	1.12	75	9	23	23	22	3.8	0.71	35.5	6.97	1854
	0.56	1.12	4	0	22	20	20	7.6	1.40	37.7	7.13	2327
DPL 105	0	0	0	0	15	14	13	12.1	2.09	58.2	11.14	1959
	0.56	0	0	0	15	14	15	11.8	2.10	55.0	10.68	2000
	0	1.12	57	12	15	14	15	6.0	1.13	42.8	7.59	1714
	0.56	1.12	1	0	14	15	14	11.3	1.94	59.2	11.13	1919
Semmes	0	0	0	0	5	6	6	14.1	3.60	87.5	14.55	1469
	0.56	0	0	0	5	6	8	11.2	2.08	55.0	10.67	1306
	0	1.12	96	98	5	1	1	5.1	0.61	21.2	1.97	0
	0.56	1.12	92	98	5	1	1	14.0	2.25	201	33.75	326
LSD[5]%			23	4	3	2	4	4.3	0.9	39.3	7.6	578

[a] Necrosis 1, 2, = % stand necrosis 14 and 21 (DAP), respectively. Population 1, 2, 3 = No. plants per meter of row at emergence, 30 DAP, and 60 DAP, respectively. FW and DW 1, 2 = average plant fresh and dry weight 30 DAP and 60 DAP, respectively. T = triapenthenol; M = metribuzin.

Table 3. The effect of the Triapenthenol*Metribuzin interaction on soybean growth 14 days after planting and yield.

Treatment[a]	Necrosis (%)	Necrosis (%)	Plant FW (g/plant)	Plant DW (g/plant)	Yield (kg/ha)
Control	0	0	12.0	2.0	2089
Triapenthenol	0	0	9.4	1.6	2093
Metribuzin	63	49	3.9	0.7	1411
Triapenthenol and metribuzin	19	27	7.7	1.3	1684
LSD5%	23	18	4.4	0.8	572

[a] Triapenthenol at 0.56 kg ai/ha; metribuzin at 1.12 kg ai/ha.

The Date*Triapenthenol interaction showed that the FW and DW of the plants from the June planting were significantly greater than those from the May planting. Triapenthenol-treated plants tended to have an increased survival rate 30 DAP. Soybeans planted in May received more benefit from this aspect of plant growth regulation.

Metribuzin Effect

Metribuzin alone at 1.12 kg ai/ha caused a high incidence of stand necrosis both 14 and 21 DAP, significantly reduced final plant stand, and reduced plant FW and DW 30 DAP. By 60 DAP, the effect of metribuzin had diminished sufficiently to compensate for early weight losses. This compensated growth may have been the result of increased photosynthetic activity (Vavrina et al. 1984), the beneficial environment (fertility, soil water, etc.), or strong competition. The Date*Metribuzin interaction indicated that the greater vigor of June-planted soybeans tended to reduce necrotic injury 21 DAP and FW loss 30 DAP caused by metribuzin. This effect was further modified by the environment. Heavy rains during the first 21 days of the 5/21/85 planting provided for leaching of metribuzin into the root zone of soybeans, resulting in greater herbicide injury levels 21 DAP. New growth in the 7-day period following the 21-DAP sample was free of injury across cultivars and dates, precluding further injury sampling.

*Triapenthenol*Metribuzin Interaction*

The triapenthenol plus metribuzin treatment reduced necrotic injury to soybean seedlings by approximately 30% at 14 DAP and 25% at 21 DAP (Table 3) when compared to metribuzin alone. The addition of triapenthenol to the metribuzin treatment tended to reduce weight loss exhibited in soybean seedlings from metribuzin treatment alone. Plant FWs and DWs from the triapenthenol plus metribuzin combination at 30 and 60 DAP approached and often exceeded the FWs and DWs of the triapenthenol treatment alone. The Date*Triapen-

Table 4. Effect of the Metribuzin*Cultivar interaction on early-season soybean growth.

Cultivar	Metribuzin rate (kg/ha)	Necrosis 14 DAP[a] (%)	Necrosis 21 DAP (%)	Population loss[b] (no./m)
Essex	0	0	0	0
	1.12	25	21	2
Braxton	0	0	0	0
	1.12	21	20	1
Centennial	0	0	0	0
	1.12	36	26	4
DPL 105	0	0	0	0
	1.12	34	36	2
Semmes	0	0	0	1
	1.12	94	97	5
LSD 5%		23	18	5

[a] DAP = days after planting.
[b] Population loss = the population at emergence minus the population at 60 DAP.

thenol*Metribuzin interaction indicated that this trend was more prevalent in the June-planted soybeans.

Cultivars

Metribuzin injury segregated along genetically defined lines, as was expected. On either planting date, Braxton and Essex received the least injury, Centennial and Delta Pine 105 received moderate injury, and Semmes received the most injury. Therefore, a significant metribuzin-cultivar interaction occurred for injury 14 and 21 DAP (Table 4). The Metribuzin*Cultivar interaction showed a soybean stand loss across cultivars at both dates. Stand loss was greatest in Semmes (the most metribuzin susceptible). The Triapenthenol*Cultivar interaction on injury showed a consistent reduction of metribuzin induced necrotic injury when triapenthenol was added in combination (Table 5). This effect was more dramatic when viewed within individual cultivars (Table 2), sometimes reducing metribuzin induce injury by 80–100%. The triapenthenol-cultivar interaction indicated that the triapenthenol treatment could not reduce metribuzin-induced stand reduction to susceptible plants within cultivars. The antidotal property conveyed by triapenthenol extended across the genetically defined lines of tolerance to metribuzin by safening all cultivars except Semmes.

Plant population at emergence was unaffected by treatment across cultivars; however, differences between cultivars occurred regardless of precision seeding. Semmes seed was believed to have been improperly stored and resulted in <50% germination. Surviving Semmes plants grew without competition and resulted in plants with unrepresentative weights when compared to other cultivars. Furthermore, while most cultivars exhibited the precision row rate of 16 seeds per meter, the Centennial seeding rate was 22 seeds per meter.

Table 5. The effect of the Triapenthenol*Cultivar interaction on early-season soybean growth.

Cultivar	Triapenthenol rate (kg/ha)	Necrosis 14 DAP[a] (%)	Necrosis 21 DAP (%)	Population loss[b] (no./m)
Essex	0	24	16	1
	0.56	1	5	1
Braxton	0	21	17	1
	0.56	0	3	1
Centennial	0	35	22	2
	0.56	2	5	3
DPL 105	0	33	23	1
	0.56	5	14	1
Semmes	0	47	49	1
	0.56	46	48	2
LSD 5%		23	18	N.S.

[a] DAP = days after planting.
[b] Population loss = the population at emergence minus the population at 60 DAP.

This result was consistent on both planting dates and was apparently due to smaller seed size affecting multiple seed placement. This artificial population difference resulted in consistent effects between cultivars throughout the study and further affected plant FW and DW determinations.

*Date*Cultivar Interaction*

The Date*Cultivar interaction proved significant, because plant reaction to metribuzin was different across dates. The 14 DAP injury was essentially the same in both the May and June planting, but injury did not advance at 21 DAP in June-planted soybeans. Differences between and within cultivar plant populations resulted in a significant Date*Cultivar interaction on population at emergence and 30 and 60 DAP. A significant Date*Cultivar interaction on DW 30 DAP occurred, with weight increasing in the June planting.

Yield

Soybean cultivar yields across treatments were not significantly affected by date (Table 6). Cultivar yield was negatively correlated with injury ($p = 0.01$) and positively correlated ($p = 0.01$) with population, FW, and DW at 30 DAP.

Triapenthenol treatment increased yield in some cultivars and reduced yield in others; metribuzin consistently reduced yield in all cultivars. The 1.12 kg ai/ha rate of metribuzin was approximately 3.5 times greater than that recommended for soybeans on coastal soils (French 1984). The yield reduction from metribuzin treatment was therefore as expected.

The triapenthenol plus metribuzin treatment tended to provide yields commensurate to the control but generally not greater than the 1.12 kg metribuzin treatment alone (Table 3). This may have been the result of the triapenthenol

Table 6. Statistical determination for significance of treatment on yield for the cultivar/triapenthenol plus metribuzin study and the Pearson correlation of yield to measured parameters over all data.[a]

		Pearson correlation for yield		
Model	Yield	Parameter	Correlation	Significance level
D	30.78	Injury 1	−0.43	0.0001
Rp (D)	458.75**	Injury 2	−0.45	0.0001
R	72.67*	Pop 1	0.37	0.0001
M	1133.21**	Pop 2	0.47	0.0001
T*M	69.13*	Pop 3	0.42	0.0001
C	857.07**	Pop 3–1	0.13	0.0546
T*C	51.21**	FW 1	0.40	0.0001
M*C	47.45**	DW 1	0.34	0.0001
T*M*C	9.61	FW 2	−0.08	0.2844
D*T	19.94	DW 2	−0.03	0.6935
D*M	12.06			
D*T*M	8.77			
D*C	36.19*			
D*T*M*C	14.81			
Error	13.47			

[a] T = Triapenthenol at 0.56 kg ai/ha; M = metribuzin at 1.12 kg ai/ha; D = date; C = cultivar.
** Significance at $p = 0.01$.
* Significance at $p = 0.05$.

plus metribuzin treatment not alleviating the population reduction across cultivars caused by the high rate of metribuzin. Where the triapenthenol plus metribuzin combination provided greater yields than the metribuzin treatment alone, the effect was not consistent over date by cultivar.

While triapenthenol reduced visual injury, it did not completely alter the metribuzin effect on yield reduction at the (excessive) 1.12 kg ai/ha rate. Cultivar itself maintains the overriding control on soybean yield with respect to metribuzin susceptibility or tolerance.

Discussion

The manipulation of crop physiology through plant growth regulation for the betterment of agriculture and the advancement of plant physiology goes much deeper than retarded growth for the control of lodging. Plant growth regulation may provide unique solutions to some other important agricultural questions. Overstepping genetically defined bounds to induce herbicide tolerance is of great importance. These studies aptly define an antidotal capacity conveyed over genetically defined barriers, though admittedly to varying degree, by anti-gibberellin plant growth regulators. The results of this 3-year study were variable across seasons and planting dates; however, they essentially verified the existing trend of triapenthenol safening.

A similar pattern of safening has been exhibited with the use of daminozide

in potato by Phatak et al. (1985). As in the present study, potato cultivars have a genetically defined response to metribuzin application also. Daminozide, when applied foliarly 14 days prior to metribuzin application, safened all potato varieties in that study against induced injury.

Though the mechanism of safening is the subject of another paper in this series, this observation remains. The application of antigibberellin plant growth regulators can safen both Solanaceae and Leguminosae crops against the unique photosynthetic inhibiting herbicide metribuzin.

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