Simulated Insect Defoliation of Seedlings and Productivity of Winter Small-Grain Crops[1]

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ABSTRACT Insects, such as grasshoppers, *Spodoptera* spp. armyworms and flea beetles, occasionally defoliate seedlings of autumn-planted small grain crops. Seedlings of wheat, *Triticum aestivum* L., barley, *Hordeum vulgare* L., oats, *Avena sativa* L., rye, *Secale cereale* L., and *triticale, X Triticosecale* Wittmack, were mechanically clipped at the soil surface to simulate insect leaf injury for various periods after planting up to the 1-, 2-, and 4-leaf stages. Defoliation up to the 4-leaf stage (i.e., ≥ 30 days after planting) delayed spike emergence of all crops by several days. Seedling defoliation generally had little adverse effect on grain yield and test weight of rye in any year and reduced yield of triticale in one of three years. Furthermore, plants of both species defoliated in the 2- and 4-leaf stages were less severely damaged by cold temperatures and yielded as much or more than nondefoliated plants when late freezes occurred. Seedling defoliation up to the 4-leaf stage also had little negative effect on grain yield and test weight of wheat. Grain yield of barley and oats declined with increasing length of defoliation period in two of three seasons with most of the reduction occurring when defoliation exceeded 20 days. Results imply that seedling defoliation up to the 4-leaf stage has little effect on grain yield and test weight of winter wheat, rye, and triticale. Defoliation only adversely affected yield of barley and oats when it occurred beyond the 2-leaf stage. As long as plant stand is not reduced, economic thresholds for seedling pests of winter small-grain crops that do not allow for the loss of most leaf tissue for several weeks after planting probably are too conservative.

KEY WORDS Wheat, oats, barley, rye, triticale, insect, damage, seedling defoliation, simulated defoliation.

Insect defoliators occasionally damage seedlings of winter small-grain crops that are grown for grain or forage production in the southeastern United States. Insect pests including grasshoppers, *Melanoplus* spp., the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), flea beetles (various species), and thrips, primarily *Franklinella* spp., occasionally cause feeding injury or defoliate small grain seedlings (Buntin and Hudson 1989). Although economic thresholds are available for insect pests of small-grain seedlings (Buntin and Hudson 1989), these thresholds are nominal (*sensu* Poston et al. 1983) in that

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they are derived primarily from the experience of pest managers and are not generated directly from yield loss studies. These nominal thresholds are conservative and typically represent pest numbers that would cause substantially less than complete defoliation of seedlings.

The effect of seedling defoliation by insects on the production of winter small grain crops has not been assessed. Studies with autumn-planted wheat in the southern U. S. have found that mechanically simulated and actual defoliation by livestock has little adverse effect on grain yield if grazing ceases before the beginning of stem elongation (Dunphy et al. 1982, Winter and Thompson 1987, Worrell et al. 1992). These findings suggest that winter small-grain crops may tolerate extensive defoliation during the vegetative growth period. Simulated grasshopper defoliation has been shown to reduce grain yield of spring-planted wheat, *Triticum aestivum* L., when injury occurs in the tillering or stem elongation stages of plant development (White 1946, Pickford and Mukerji 1974, Mukerji et al. 1976, Weiss 1987). However, Weiss (1987) found that mechanical clipping to simulate complete defoliation by grasshoppers usually had little effect on grain yield and quality of spring-planted wheat, barley, *Hordeum vulgare* L., and oats, *Avena sativa* L., when defoliation occurred in the 2-leaf or 4-leaf stages. Capinera and Roltsch (1980) found that manual clipping and actual defoliation by the grasshopper, *Melanoplus sanguinipes* (F.), caused small (i.e., 5-10%) but significant differences in regrowth and tillering of winter wheat seedlings, although grain yield was not measured. If one assumes that the primary effect of leaf injury by chewing insects is loss of leaf area for light interception and photosynthate production, then leaf clipping should adequately simulate insect injury causing loss of leaf tissue. Therefore, to determine how long small-grain seedlings could tolerate complete defoliation, the yield response of winter small-grain crops to simulated insect defoliation was examined for various periods after planting.

Materials and Methods

The study was conducted in 1989/1990, 1990/1991, and 1992/1993 growing seasons at the Southwest Branch Experiment Station near Plains, GA. Soil was a Greenville sandy loam and was conventionally prepared by chisel plowing and disk harrowing in all years. The plot area was fertilized at 550 kg/ha with 5-10-15 (N-P-K) granulated fertilizer before planting; 77 kg of nitrogen was broadcast applied as ammonium nitrate in early February. Crops studied were wheat, triticale, *X Triticosecale* Wittmack, barley, and oats in all years and rye, *Secale cereale* L., in the first two seasons. Two cultivars of whet were included in the second two seasons. Wheat cultivars were 'Saluda' in 1989, 'Saluda' and 'Coker 9766' in 1990, and 'GA-Gore' and 'Coker 9835' in 1992. 'Volbar' barley was used in the first two seasons, and 'Venus' barley was planted in 1992. 'Wrens Abruzzi' rye, 'Beagle 82' triticale, and 'Coker 227' oats were used in all years.

Seed of all crops was sown in 18-cm rows using a small-plot grain drill at the rate of 98 kg/ha. Plots measured 5 rows (0.9 m) by 3.0 m and were planted on 13 November 1989, 8 November 1990, and 19 November 1992. Defoliation was simulated by clipping all foliage above the soil with scissors. Defoliation occurred at 12, 23, and 38 days after planting in 1989, 10, 20, and 33 days after planting in 1990, and 10, 20, and 30 days after planting in 1992. These periods corresponded with the 1-leaf, 2-leaf, and 4-leaf stages, respectively, in each year. In the second two seasons, defoliation was imposed at each specified time until the desired duration of defoliation occurred. For example, plants in the 4-leaf-stage defoliation treatments were completely defoliated at 10, 20, and 33 days after planting in 1990 and at 10, 20, and 30 days after planting in 1992. A split-plot experimental design was used with crops arranged as whole plots in a randomized complete block design and defoliation treatments arranged as split plots. Whole plots were replicated four times in the first two seasons and six times in 1992/1993, but because of poor stand establishment one block of the oats and triticale was dropped in the third season.

In the first two seasons, foliage clipped from one row in each plot was collected, dried and weighed. Freezing temperatures causing visible cold injury in some plots occurred on 16 - 17 February 1991 and 13 - 15 March 1993. Plots were rated for cold injury 12 days after symptoms became evident. Injury was rated using a relative scale of: 0 = no injury, 1 = injury to leaf margins and tips, 2 = extensive leaf injury and some stem injury, 3 = extensive stem injury with the leaf whorl of primary tillers being killed, 4= severe injury of stems and leaves with some loss of plant stand, and 5 = complete loss of plant stand. Plots were harvested with a Hege small-plot combine (Model 125C, H & N Equipment, Colwich, KA) on 8 June 1990, 31 May 1991, and 2 June 1993. Seed weight, test weight, and moisture content were measured. Seed yield was adjusted to 12% moisture content for all crops.

The median cold injury rating was determined, but ratings were not analyzed statistically. Yield and test weight data were analyzed by crop and year with two-way analyses of variance, and means were separated with least significant difference (LSD) procedure (SAS Institute 1985). To compare yield loss relationships between years, yields of all plots were expressed as a percentage of the mean value of the nondefoliated check in each trial. Linear regression (PROC REG, SAS Institute 1985) was used to determine the relationship between the length of defoliation in days and percent yield for each crop and year. Differences of linear slopes between years was assessed for each crop using a combined analysis of variance (PRCO GLM, SAS Institute 1985) where the interaction of year by linear effect for defoliation length was tested for homogeneity of slope values (Snedecor and Cochran 1967). If slopes were not significantly different ($P > 0.05$), a linear regression was calculated with data from all years.

Results

Cold temperature injury was not observed in any crop in the first season. Cold temperatures (≤-6°C) causing visible injury occurred on the nights of 16 - 17 February 1991 and 13 - 15 March 1993 (Table 1). The early maturing crops of rye and triticale and to lesser extent 'Coker 9835' wheat in 1993 and oats in both seasons were injured by the cold temperatures. Injury in these crops was most severe in both years in the nondefoliated and 1-leaf stage defoliated plots with plants defoliated at the 4-leaf stage having substantially reduced cold injury symptoms.

Table 1. Median rating of cold temperature injury during late winter in two seasons.

Defoliation treatment	Cold Injury Rating					
	Wheat-1*	Wheat-2*	Barley	Oats	Triticale	Rye
		1990/1991				
Nondefoliated	0	1	0	2	3	3
1-leaf stage	0	1	0	2	3	3
2-leaf stage	0	0	0	1	2	2
4-leaf stage	0	0	0	0	1	1
		1992/1993				
Nondefoliated	0	2	0	1	3	-
1-leaf stage	0	2	0	1	3	-
2-leaf stage	0	1	0	0	2	-
4-leaf stage	0	0	0	0	1	-

* Wheat cultivars were 1 = 'Saluda' and 2 = 'Coker 9766' in 1990/1991 and 1 = 'GA Gore' and 2 = 'Coker 9835' in 1992/1993.

Although heading dates were not quantified, observations indicated that defoliation at the 1-leaf stage did not delay the rate of maturity of any crop. However, defoliation at the 2-leaf stage usually delayed heading of most crops by 1 to 3 days, and defoliation at the 4-leaf stage (30 or more days) usually delayed heading of most crops by 2 to 6 days in all years. Consequently, plants defoliated at the 2- and 4-leaf stages were less mature than nondefoliated plants when cold temperatures occurred in 1991 and 1993.

Defoliation did not significantly affect grain yield of wheat, rye, or barley in 1989/1990 (Table 2). Compared with the nondefoliated check, defoliation at 2- and 4-leaf stages significantly reduced yield of triticale. Yield of oats also declined significantly when defoliation occurred at the 4-leaf stage. Grain yields of defoliation treatments were not significantly different for any crop in 1990/1991, except for barley (Table 2). Barley grain yields of all defoliation treatments were lower than the nondefoliated check. Nevertheless, although not statistically significant, yield of the 2- and 4-leaf-stage defoliation treatments of triticale and rye were substantially greater than the nondefoliated check. Yields of the 4-leaf stage treatment were greater by 57.2% and 27.4% than the nondefoliated plots for triticale and rye, respectively. Grain yields of defoliation treatments also were not significantly different for any crop except 'Gore' wheat in 1992/1993 (Table 2). Defoliation of Gore wheat up to the 2- and 4-leaf stages significantly reduced yield as compared with no and 1-leaf-stage defoliation.

Grain test weight is a measure of grain quality and represents a combination of seed weight and packing efficiency of grain (Finney et al. 1987). Test weights of triticale, rye, and oats were not significantly affected by seedling defoliation in any year (Table 3). Test weight of barley was not significantly affected by

Table 2. Effect of seedling defoliation on grain yield of winter small grain crops in three seasons at Plains, GA.*

Defoliation treatments	Mean (±SE) grain yield (kg/ha)					
	Saluda** wheat	Coker 9766† wheat	Barley	Oats	Triticale	Rye
			1989/1990			
Nondefoliated	3623 ± 289 a	–	5249 ± 310 a	4761 ± 228 a	5326 ± 75 a	4100 ± 135 a
1-leaf stage	3988 ± 153 a	–	5050 ± 253 a	4646 ± 178 a	5091 ± 95 ab	3910 ± 107 a
2-leaf stage	3645 ± 150 a	–	4572 ± 199 a	4217 ± 97 ab	4923 ± 92 b	3637 ± 74 a
4-leaf stage	3635 ± 233 a	–	4441 ± 118 a	4072 ± 118 b	4623 ± 52 c	3799 ± 205 a
LSD	NS	–	NS	561	254	NS
F value	0.85	–	3.10	3.57 a	13.63 b	1.52
			1990/1991			
Nondefoliated	2221 ± 157 a	2989 ± 256 a	4303 ± 263 a	3906 ± 165 a	1345 ± 113 a	1889 ± 219 a
1-leaf stage	2089 ± 89 a	2963 ± 260 a	3559 ± 228 b	4133 ± 225 a	1671 ± 423 a	1881 ± 109 a
2-leaf stage	1791 ± 88 a	2479 ± 186 a	2980 ± 174 b	3883 ± 217 a	2174 ± 196 a	2095 ± 215 a
4-leaf stage	2088 ± 164 a	2434 ± 391 a	3350 ± 85 b	4166 ± 184 a	2115 ± 184 a	2407 ± 108 a
LSD	NS	NS	684	NS	NS	NS
F value	2.44	2.39	6.80 a	1.03	2.27	2.35
			1992/1993			
Nondefoliated	4375 ± 106 a	3441 ± 104 a	6506 ± 183 a	4526 ± 299 a	3177 ± 97 a	–
1-leaf stage	4368 ± 156 a	3657 ± 106 a	6143 ± 226 a	4386 ± 225 a	3042 ± 83 a	–
2-leaf stage	4051 ± 154 b	3840 ± 68 a	6313 ± 213 a	4285 ± 179 a	3093 ± 75 a	–
4-leaf stage	4037 ± 145 b	3752 ± 127 a	6028 ± 150 a	4136 ± 307 a	3021 ± 38 a	–
LSD	235	NS	NS	NS	NS	–
F value	5.87 b	2.55	1.31	0.88	0.71	–

* Means within columns and year followed by the same letter are not significantly different ($P > 0.05$, LSD); df = 3, 6; NS = nonsignificant treatment F value; a and b indicate significant F value at $P < 0.05$ and $P < 0.01$, respectively.

** 'Gore' wheat in 1992/1993.

† 'Coker 9835' wheat in 1992/1993.

Table 3. Effect of seedling defoliation on grain test weight of winter small grain crops in three seasons at Plains, GA.*

Defoliation treatments	Mean (±SE) test weight (kg/m³)					
	Saluda** wheat	Coker 9766† wheat	Barley	Oats	Triticale	Rye
			1989/1990			
Nondefoliated	663 ± 6 a	–	564 ± 6 a	436 ± 5 a	608 ± 5 a	684 ± 1 a
1-leaf stage	675 ± 2 b	–	568 ± 2 a	436 ± 4 a	606 ± 2 a	690 ± 3 a
2-leaf stage	673 ± 5 b	–	572 ± 5 a	434 ± 5 a	603 ± 3 a	689 ± 4 a
4-leaf stage	679 ± 5 b	–	573 ± 6 a	434 ± 4 a	604 ± 2 a	690 ± 2 a
LSD	0.9	–	NS	NS	NS	NS
F	5.60 a	–	0.75	0.25	1.57	1.81
			1990/1991			
Nondefoliated	746 ± 16 a	716 ± 36 a	587 ± 5 a	516 ± 6 a	719 ± 10 a	771 ± 14 a
1-leaf stage	738 ± 13 a	722 ± 24 a	580 ± 5 ab	500 ± 9 a	742 ± 11 a	778 ± 4 a
2-leaf stage	720 ± 19 a	716 ± 18 a	557 ± 1 c	523 ± 3 a	745 ± 10 a	777 ± 15 a
4-leaf stage	752 ± 19 a	688 ± 41 a	564 ± 8 bc	520 ± 14 a	755 ± 15 a	790 ± 5 a
LSD	NS	NS	1.9	NS	NS	NS
F	1.49	0.30	5.77 a	1.18	1.40	0.51
			1992/1993			
Nondefoliated	751 ± 3a	713 ± 3 a	702 ± 6 a	540 ± 4 a		–
1-leaf stage	757 ± 3 a	723 ± 3 b	702 ± 2 a	540 ± 6 a	712 ± 3 a	–
2-leaf stage	751 ± 2 a	720 ± 2 ab	705 ± 3 a	539 ± 7 a	717 ± 4 a	–
4-leaf stage	756 ± 4 a	728 ± 2 b	692 ± 10 a	535 ± 6 a	715 ± 2 a	–
LSD	NS	0.9	NS	NS	712 ± 4 a	–
F	1.72	4.31 a	0.64	0.16	NS	–

* Means within columns and year followed by the same letter are not significantly different ($P > 0.05$, LSD); df = 3, 6; NS = nonsignificant treatment *F* value; a indicate significant *F* value at $P < 0.05$.

** 'Gore' wheat in 1992/1993.

† 'Coker 9835' wheat in 1992/1993.

defoliation treatments in two seasons, but defoliation at the 2- and 4-leaf stages reduced test weight by 3.9 and 5.1%, respectively, in 1990/1991. Seedling defoliation did not significantly affect test weight of wheat in three trials, but test weight increased significantly after defoliation in 1989/1990 and for one cultivar in 1992/1993. However, increases in wheat test weight were ≤ 2.4% in 1989/1990 and ≤ 0.8% in 1992/1993.

Slopes of linear regressions of percent yield and length of defoliation for crops in each year are shown in Table 4. Linear regressions for wheat were not significant in the first two seasons, but one cultivar showed a significant negative regression whereas the other cultivar exhibited a significant positive relationship in 1992/1993. Significant negative regressions occurred for barley and oats in two of three seasons and for triticale in one season. Conversely, grain yield increased significantly with length of the defoliation period for triticale and rye in 1990/1991. Slope values were significantly different between years for triticale ($F = 17.76$, df = 2, 45; $P < 0.001$), rye ($F = 9.11$, df = 2, 28; $P < 0.005$) and oats ($F = 4.04$, df = 2, 42; $P < 0.02$), but slopes for barley were not significantly different between years ($F = 2.14$, df = 2, 50; $P = 0.13$). Comparison of slopes for all wheat trials was significant ($F = 2.60$, df = 4, 86; $P < 0.04$), but when the trial with Coker 9835 was removed, slopes of the remaining trials were not significantly ($F = 0.96$, df = 3, 64; $P = 0.42$) different.

Discussion

Results from three seasons with the varieties used in this study indicated that winter barley and oats were more sensitive to seedling defoliation than the other small grains. Seedling defoliation for up to the 4-leaf stage (i.e., 30 days) generally had little negative effect on grain yield and test weight of wheat. Seedling defoliation had a variable effect on triticale in that defoliation caused yield to decline in the first year, increase in the second year, and not change in the third year. Likewise, grain yield of rye was not affected by defoliation in one year and increased with length of defoliation in the other year. Triticale and rye mature earlier with spike emergence usually occurring two to three weeks sooner than the other small grains in Georgia (Day et al. 1993). Typical heading dates for small grains in the upper coastal plain of Georgia are early to mid March for rye and triticale and late March to mid April for wheat, barley, and oats (Day et al. 1993). Consequently, triticale and rye often are more susceptible to and severely damaged by freezes in late February and March than the other small grain crops. Thus, when late freezes occurred, defoliated plants were less severely damaged by cold temperatures and yielded more than nondefoliated plants in the early-maturing crops of triticale and rye. Wheat, barley, and oats were not affected by these freezes or showed only moderate interaction between defoliation and cold injury because they were less mature and in a less susceptible developmental stage when cold temperatures occurred.

Because of the interaction with late freeze injury, seedling defoliation up to the 4-leaf stage after planting probably is inconsequential in early maturing small-grain crops unless pest activities reduce stand. Seedling defoliation in wheat, oats, and particularly barley may reduce subsequent yield, but significant losses occurred only in some trials and only when defoliation lasted

Table 4. Slope values and significance of linear regression of percent yield loss and duration (days) of seedling defoliation in small grain crops.

Crop	Year	b*	F	P	r^2
Wheat	1989/1990	-0.069	0.11	0.75	<0.01
	1990/1991	-0.2548	0.93	0.35	0.06
	1990/1991	-0.6477	3.03	0.10	0.18
	1992/1993	-0.3043 a	4.65	0.04	0.17
	1992/1993	+0.3243 a	5.70	0.03	0.21
	1st 4 sets	-0.2745	4.78	0.03	0.06
Barley	1989/1990	-0.4353 a	8.53	0.01	0.38
	1990/1991	-0.7048 a	8.68	0.01	0.38
	1992/1993	-0.1942	2.16	0.16	0.09
	overall	-0.4294	14.04	0.0004	0.21
Oats	1989/1990	-0.4142 b	12.36	0.003	0.47
	1990/1991	+0.1396	0.47	0.51	0.03
	1992/1993	-0.2752 b	9.37	0.009	0.40
	overall	-0.2161	4.65	0.036	0.09
Triticale	1989/1990	-0.3405 b	46.67	0.0001	0.77
	1990/1991	+2.0810 b	12.13	0.004	0.48
	1992/1993	-0.1310	1.57	0.23	0.08
Rye	1989/1990	-0.2164	3.05	0.10	0.18
	1990/1991	+0.8731 a	5.92	0.03	0.30

* b = % change in yield per day; a and b indicate significant slope at $P < 0.05$ and $P < 0.01$, respectively.

beyond the 2-leaf stage (i.e., 20 or more days after planting). Seedling pests often cause less than complete defoliation which most likely would be less injurious than the complete defoliation simulated in this study. Economic thresholds for some insect pests of small-grain seedlings in Georgia are 3.6-6.0 grasshoppers per m^2, 2 flea beetles per 30-cm of row, ≥ 3 armyworm larvae per 0.9-m^2, or when 25% of plants show defoliation (Buntin and Hudson 1989). These insect popualtions typically would produce substantially less than complete defolation. My results indicate that these economic thresholds are too conservative, and that winter small grain crops can tolerate a substantial amount of defoliation and leaf injury by seedling pests for several weeks after planting before curative management practices are justified.

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