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Surface Wheat (*Triticum aestivum*) Residues, Giant Foxtail (*Setaria faberi*), and Soybean (*Glycine max*) Yield[1]

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Abstract. **Experiments were conducted from 1992 through 1994 to determine the effect of 0 to 12 Mg ha^{-1} of surface wheat residues (SWR) on giant foxtail density and crown node length, and soybean yield. Giant foxtail density decreased as SWR increased from 0 to 12 Mg ha^{-1}. SWR of 6 to 12 Mg ha^{-1} reduced giant foxtail density by 2 to 50 % compared to bare soil. The crown node of giant foxtail was 2 cm above the soil surface with 12 Mg ha^{-1} of SWR. Frost in 1992 injured soybean more than weeds in plots with SWR while soybean in soil with no SWR was not injured. In absence of frost in 1993 and 1994, yield of weedy soybean increased 20 to 29%, respectively, with the increase of SWR from 0 to 6 Mg ha^{-1}. In weed-free plots, soybean yield was similar across all SWR levels. These results confirm the hypothesis that high levels of SWR increased soybean yield in weedy plots because of decreased giant foxtail infestation. Nomenclature: Giant foxtail, *Setaria faberi* Herrm. #[3] SETFA; soybean, *Glycine max* (L.) Merr. 'Resnik'; wheat, *Triticum aestivum* L. 'Clark.'**
Additional index words. **Conservation tillage, cover crop, crop rotation, double-crop, no-till, weed interference.**

INTRODUCTION

Crop production using no-tillage systems has increased steadily for the last three decades. Successful weed management in no-tillage systems depends on herbicides. However, weed resistance to herbicides, water contamination, impact of herbicides on nontarget organisms, as well as, some cases of reduced profit from high herbicide cost have prompted weed scientists to search for new strategies for weed management in no-till systems (10, 17, 26, 27).

Giant foxtail is the most serious grass weed in the Midwestern United States (14, 15). Four giant foxtail plants meter^{-2} reduced soybean yield 5%, and 200 plants meter^{-2} reduced soybean yield 30% (15).

Some researchers (5, 6) observed an increase in giant foxtail infestation in no-tillage, compared to conventional tillage. Mester and Buhler (16) showed that tillage distributed giant foxtail seeds in the soil profile, whereas no-tillage concentrated seeds on the soil surface. Consequently, 45% of all emerged giant foxtail plants in no-till came from seeds in the upper 1 cm of soil, contrasted with only 15% in conventional tillage (16).

Experiments conducted in Africa (11), Brazil (1), Bolivia (8), Canada (2), India (20), and United States (10, 17, 26, 27) indicate that annual weed infestation decreased as crop residue on the soil surface increased. Almeida (1) and Teasdale et al. (26) assessed weed infestation after several cover crops were killed with herbicides and provided indirect evidence for the negative relationship between crop residue levels and weed population. Other authors (2, 8, 10, 11, 17, 20, 27) varied levels of crop residue and observed reduction in number of annual weeds with high crop residues, offering direct evidence that crop residues controlled weed emergence.

The influence of surface wheat residues (SWR)[4] on giant foxtail emergence is not reported in the literature. Giant foxtail seed germination is optimum with day/night temperatures of 35/25 C (21) and decreases as temperature decreases (16, 21). High levels of SWR reduce fluctuation of soil temperature and moisture compared to conventional tillage systems (12), suggesting that high levels of SWR in no-tillage systems may affect giant foxtail emergence. The objective of this study was to determine the effects of SWR levels on giant foxtail density and crown node length, and soybean yield.

MATERIAL AND METHODS

Seven experiments were conducted from 1992 through 1994 at the Purdue Agronomy Research Center in West Lafayette, Indiana. The soil was a Chalmers silt clay loam (Haplaquoll:Molissol) with 3.5% organic matter and pH 6.7. Rainfall and temperature data for the experimental period were provided by the Midwest Agricultural Weather Service Center from instruments located 1000 m from the experiments (Table 1).

1992 experiments. Two experiments, 92A and 92B, where conducted in a field were soil had been plowed the previous fall and disked twice before the beginning of the experiment. Experiment 92A was initiated May 21, when wheat straw harvested the previous year and stored in a barn was weighed and spread by hand on the soil surface in 2 by 2 m plots. Treatments with SWR equivalent to 0, 2, 4, 6, 8, 10, and 12 Mg ha^{-1} were organized in a randomized complete block with five replicates. Giant foxtail population was measured in 0.17 m^2 quadrats in the middle of each plot, 10, 30, and 60 DAT. The distance from the soil level to the crown node of five foxtail plants per plot was measured 60 DAT.

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 W. University, Champaign, IL 61821-3133.

[4]Abbreviations: SWR, surface wheat residues; DAT, d after treatment; Mg, 1,000 kg.

Table 1. Average monthly air temperature and rainfall during the crop seasons for 1992 through 1994, compared to 30 yr average, at West Lafayette, IN.

Month	Temperature				Rainfall			
	1992	1993	1994	Avg.[a]	1992	1993	1994	Avg.[a]
	C				cm			
May	20	17	14	16	2.5	9.2	5.4	9.3
June	19	20	22	21	2.9	15.5	14.0	9.6
July	21	23	22	24	28.2	12.9	13.7	9.1
August	19	22	19	22	3.1	10.0	12.1	9.8
September	18	16	17	19	10.7	8.4	5.1	7.3

[a]Avg. = 30 yr average.

In experiment 92B, soybean 'cv. Resnik' was planted the last week of May at 60 kg ha^{-1} in 75 cm rows. Treatments were SWR at 0 and 7 Mg ha^{-1} and sub-treatments were weedy and weed-free soybeans. Giant foxtail in weed-free sub-treatments was controlled with 250 g ha^{-1} of sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one), and the few broadleaf weeds were hand removed. The experiment was organized in a randomized complete block with four replicates. Size of each sub-plot was 3 by 10 m. Soybean grain yield was determined after plants in the two middle rows were harvested with a combine and grain moisture was adjusted to 13%.

1993 experiments. Two experiments, 93A and 93B, were conducted in a no-till soybean-wheat rotation. In both experiments, wheat 'Clark' was planted in soybean stubble in the fall of 1992 at 125 kg ha^{-1}. The following March, nitrogen fertilizer was applied at 110 kg ha^{-1} (220 kg ha^{-1} urea). Glyphosate (*N*-(phosphonomethyl)glycine) at 900 g ha^{-1} was applied to kill the wheat in mid-May.

In experiment 93A, soybean was planted the last week of May, using the same cultivar, seed rate, and row spacing as in 92B. After planting, standing wheat on all plots was cut with a sickle mower. SWR were adjusted to 0, 3, 6, and 9 Mg ha^{-1} according to the procedure described by Crutchfield (10); namely, excess straw was weighed and removed and needed straw was weighed and spread by hand. Weedy and weed-free sub-treatments were established as in experiment 92B. The experimental design, sub-plot sizes, and determination of soybean yield were conducted as in experiment 92B. Giant foxtail populations were determined 10, 30, and 45 DAT, as in experiment 92A.

Experiment 93B was conducted (without crop) in desiccated wheat late in the spring to evaluate possible weed infestation in a double-crop situation. In mid-June, 250 g ha^{-1} sethoxydim was sprayed to control foxtail. Wheat straw was dried and weighed June 15. The next day, SWR were adjusted to 0, 3, 6, 9, and 12 Mg ha^{-1} on 2 by 2 m plots. Treatments were in a randomized complete block with three replicates. Giant foxtail populations were determined 15 and 60 DAT.

1994 experiments. Three experiments, 94A, 94B, and 94C, were conducted in a no-till soybean-wheat rotation. In all experiments, Clark wheat was planted in soybean stubble in the fall of 1993 at 125 kg ha^{-1}. The following March, nitrogen fertilizer was applied at 110 kg ha^{-1} (220 kg ha^{-1} urea). Experiment 94A was an exact repetition of experiment 93A, with giant foxtail populations counted 20, 35, and 50 DAT.

In experiment 94B soybean was double cropped after wheat was desiccated in mid-June with paraquat (1,1′-dimethyl-4-4′bipyridinium ion) at 900 g ha^{-1} and harvested 1 wk later. Soybean was planted June 23 at 70 kg ha^{-1} in 75 cm rows. Treatments and sub-treatments were as described for experiment 93A. The experimental design, sub-plot sizes, and determination of soybean yield were conducted as in experiment 92B. Giant foxtail populations were counted 15, 30, and 45 DAT.

In experiment 94C, pinto-beans was planted June 23 at 150 kg ha^{-1} in 75 cm rows, after wheat desiccation and harvest as in experiment 94B. On July 7, nitrogen fertilizer was applied at 50 kg ha^{-1} (100 kg ha^{-1} urea). Treatments and sub-treatments were as described for experiment 93A. The experimental design, sub-plot sizes, and determination of giant foxtail populations were as in experiment 94B.

Statistical analysis. All data were subjected to ANOVA. To accommodate heterogeneity of variance, ANOVA also was performed on data transformed by log (x + 1), where x was evaluated data. LSD (0.05) was used to compare means.

RESULTS AND DISCUSSION

The spring of 1992 was dry and cold, with minimum temperatures below the 30 yr average monthly minimum temperature (Table 1). An unusual frost occurred June 20, 1992, 20 d after soybean emergence. In 1993 and 1994, the growing season was extremely wet, with rainfall above the 30 yr average monthly rainfall.

Foxtail density. Despite differences in weather among yr, giant foxtail density was reduced at high levels of SWR, in all experiments 10 to 20 (Table 2), 30 to 35 (Table 3), and 45 to 60 DAT (Table 4). Fifteen ANOVAS, from a total of 17, indicated significant linear correlation between level of SWR and giant foxtail density (data not shown). However, the linear equation did not follow biological responses observed. Quadratic or higher order polynomial responses had very low mean squares (indicating low regression coefficient) and were observed in only nine and four cases, respectively (data not shown). Other researchers (10, 17, 27) had similar problems fitting an equation to observed results.

Three trends were observed in the results. First, in all assessments at the three evaluation times for experiments 92A and 93B

Table 2. Giant foxtail density 10 to 20 d after treatment.

Straw	Giant foxtail density in experiment					
	92A	93A	93B	94A	94B	94C
$Mg\ ha^{-1}$	plants m^{-2}					
0	167	47	53	131	49	25
2	105	—	—	—	—	—
3	—	13	60	26	10	5
4	115	—	—	—	—	—
6	22	11	39	7	9	6
8	2	—	—	—	—	—
9	—	7	6	3	7	9
10	7	—	—	—	—	—
12	27	—	5	—	—	—
LSD 0.05	66	27	12	60	26	12
Tillage	Disk	No-till	No-till	No-till	No-till	No-till

Table 4. Giant foxtail density 45 to 60 d after treatment.

Straw	Giant foxtail density in experiment					
	92A	93A	93B	94A	94B	94C
$Mg\ ha^{-1}$	plants m^{-2}					
0	508	124	72	121	64	50
2	584	—	—	—	—	—
3	—	109	63	7	29	42
4	631	—	—	—	—	—
6	184	41	53	13	101	26
8	198	—	—	—	—	—
9	—	43	23	5	23	42
10	297	—	—	—	—	—
12	76	—	12	—	—	—
LSD 0.05	251	71	17	79	ns[a]	ns
Tillage	Disk	No-till	No-till	No-till	No-till	No-till

[a]ns = not significant.

(Tables 2 through 4), the emergence of giant foxtail was similar for SWR below 4 Mg ha^{-1}, decreased sharply with increment of SWR to 6 Mg ha^{-1}, and was similar for SWR above 6 Mg ha^{-1}. Second, in the last assessment in experiments 94B and 94C (Table 4), giant foxtail density did not respond to level of SWR. Third, for all other dates of assessment, giant foxtail emergence decreased sharply from 0 to 3 Mg ha^{-1}, and was similar for SWR greater than 3 Mg ha^{-1}. The amount of SWR needed to reduce foxtail density compared with bare soil was 6 Mg ha^{-1} for 1992 and 1993 experiments, and 3 Mg ha^{-1} for 1994 experiments (Table 2 through 4).

In experiments 94B and 94C, SWR up to 9 Mg ha^{-1} was not enough to maintain reduced weed density through mid-August. At least four factors account for the late emergence of giant foxtail in these experiments: available niche because plots with high SWR were practically weed-free (Tables 2 and 3), favorable climatic conditions for germination in August (Table 1), lack of canopy closure, and decomposition of SWR.

In experiment 93A and 94A, soybean was planted before June and the canopy closed about 50 DAT. In experiments 94B and 94C, soybean and edible-beans (*Phaseolus vulgaris* L.) were planted June 23 and did not grow enough to close the canopy until harvest. Several authors (4, 6, 7) showed that reduction of spacing between crop rows accelerated canopy closure and helped control weeds. We speculate that a reduction in row spacing in our experiments would help SWR decrease weed density.

Table 3. Giant foxtail density 30 to 35 d after treatment.

Straw	Giant foxtail density in experiment				
	92A	93A	94A	94B	94C
$Mg\ ha^{-1}$	plants m^{-2}				
0	298	214	108	92	82
2	300	—	—	—	—
3	—	132	5	12	18
4	316	—	—	—	—
6	73	64	5	17	12
8	90	—	—	—	—
9	—	44	6	13	10
10	81	—	—	—	—
12	23	—	—	—	—
LSD 0.05	240	93	54	63	66
Tillage	Disk	No-till	No-till	No-till	No-till

Stott et al. (23) showed that wheat residues decompose to 65% of their original weight 5 wk after harvest. Their work, performed in part in West Lafayette, IN, indicated that SWR level does not affect wheat straw decomposition rate up to 20 wk after harvest (23). Therefore, experiments 94B and 94C had reduced SWR 45 DAT and this, combined with favorable weather, allowed germination of foxtail in plots without weeds, leveling the response observed for all SWR levels.

A decrease in weed infestation with increasing amount of crop residues was observed by others (1, 2, 10, 11, 20, 25, 26, 27). Factors that may regulate these results for several annual weeds are quantity and quality of light under straw (2, 25), soil temperature (21, 25), soil moisture (24), release of allelochemicals by the straw (1, 21, 26), levels of nutrients (mainly nitrogen) (3), oxygen in the soil (2), and microbial activity in the soil (3, 9).

Location of foxtail crown node. Crown nodes of giant foxtail in bare soil were located at the soil surface. However, crown nodes were above the soil surface and in the middle of the straw, with increasing SWR levels (Table 5). Location of giant foxtail crown nodes above the soil in treatments with SWR coincides with results obtained for wheat by Cochran et al. (9). These authors observed that the crown node of no-tilled winter wheat was positioned 20 mm above the soil. Murray et al. (18) observed the length of the first internode of foxtail plants was 25, 50, and 80 mm when seeds were planted 3, 6, or 10 cm deep, respectively. SWR is a barrier to foxtail emergence and at 12 Mg ha^{-1} is a 5 cm thick layer on the soil surface.

Two theories may explain the cause of plant internode elongation in plants under canopy. First, the red to far-red light ratio decreased when sunlight crossed the canopy, consequently, more far-red light would stimulate internode elongation (22). The second theory proposes that a canopy reduces the amount of blue

Table 5. Giant foxtail crown node length 50 to 60 d after treatment.

Straw	Giant foxtail crown node length in experiment 92A	94A
Mg ha^{-1}	mm	
0	0	1
2	3	—
3	—	7
4	11	—
6	17	11
8	16	—
9	—	13
10	19	—
12	19	—
LSD 0.05	5.5	6.1
Tillage	Disk	No-till

light, a known inhibitor of internode growth, thus less blue light reaches the cryptochromes, allowing internode elongation (22). It is possible that increased length of the foxtail crown node above the soil, due to SWR, may make plants more susceptible to mechanical control by a rolling cultivator adapted to no-till.

Soybean yield. *Full season planting.* Climatic conditions influenced how SWR affected soybean yield (Figure 1). In 1992 we could not demonstrate that SWR can increase crop yield because frost injured soybean plants in plots with SWR. In 1993 and 1994, SWR reduced foxtail density and consequently increased soybean yield (Figure 1).

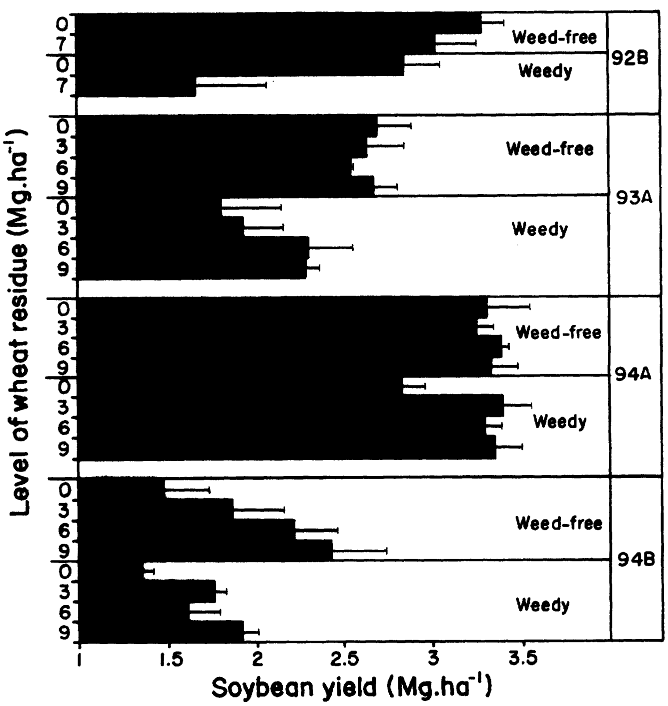

Figure 1. Effect of surface wheat residues and weediness on soybean yield in 1992, 1993, and 1994 (bars represent standard error of the mean).

In 1992, a frost occurred 20 d after soybean emergence and caused injury to 30% soybeans in SWR treatments, without causing significant harm (injury < 4%) to soybeans with no SWR. Frost injury interacted with foxtail interference decreasing soybean yield in weedy plots with SWR. In weed-free treatments, soybean yield was not affected by straw, but in weedy plots, soybean yield was reduced 42% in areas with SWR compared to areas with no residue (Figure 1). The harmful effect of SWR to soybean yield in weedy plots occurred because frost injured the crop and did not affect giant foxtail. Soybean plants in SWR treatments regrew from lateral buds and produced two main branches. Soybean plants in bare soil had only one main branch. Patterson & Flint (19) found a stronger influence of cold temperatures on cotton (*Gossypium hirsutum* L.) than on weeds, giving weeds a competitive advantage. Frost probably caused more damage to soybeans because residues insulated soil and prevented heat from escaping and protecting plants (13).

In 1993, soybean yield was constant across all levels of SWR in weed-free plots, but was decreased in weedy plots as SWR decreased (Figure 1). SWR of 6 and 9 Mg ha^{-1} reduced weed infestation compared to bare soil and increased soybean yield (Figure 1). This conclusion is supported by the significant correlation (88%) between soybean yield and weed infestation. The effect of SWR was isolated from weed infestation (SWR levels in weed-free treatments) and did not affect soybean yield. The logical conclusion is that reduction of weed infestation by SWR increased soybean yield.

In experiment 94A, soybean yield was reduced only in weedy plots on bare soil whereas SWR did not affect soybean yield under weedy or weed-free conditions (Figure 1, 94A). With SWR the weed infestation was very low (Tables 2 through 4) and did not interfere with soybeans. With bare soil, weed infestation was high enough to reduce soybean yield (Figure 1, 94A). Again, the high correlation (84%) between soybean yield and weed infestation supports the hypotheses that SWR reduced giant foxtail infestation and increased soybean yield.

Double-crop planting. Soybean yield increased with increment of SWR in weedy and weed-free treatments (Figure 1, 94B). At the highest level of SWR, soybean yield was 25% higher in weed-free than in weedy plots (Figure 1, 94B). The canopy never closed and soybeans that were weed-free probably intercepted more light than weedy soybeans. This could partially explain, the increased soybean yield to high SWR levels in weed-free compared to weedy plots. Maximum soybean yield with double cropping (Figure 1, 94B) was 1 Mg ha^{-1} less than full-season soybean yield (Figure 1, 94A).

This research showed that increasing the SWR affected giant foxtail density and morphology, and crop response to foxtail infestation. Giant foxtail density was reduced as SWR increased to 12 Mg ha^{-1}. Compared to bare soil, at least 6 Mg ha^{-1} of SWR was necessary to reduce giant foxtail density 50%. The crown node of giant foxtail was observed 2 cm above the soil with 12 Mg ha^{-1}. Environment influenced how SWR affected weed-crop interaction. SWR increased weed interference in 1992 because frost injured soybean plants with SWR and did not harm foxtail plants. When the environment was favorable to crop development in 1993 and 1994, soybean yield increased with increasing levels of SWR with weeds because of reduced foxtail infestation.

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